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OF OUTER SPACE

REPORT ON THE UNITED NATIONS/ESCAP/UNDRO WORKSHOP ON THE APPLICATIONS OF SPACE TECHNIQUES TO COMBAT NATURAL DISASTERS, ORGANIZED IN COOPERATION WITH THE GOVERNMENT OF CHINA

(Beijing, 23-27 September 1991)

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INTRODUCTION

A. Background and objective

1. At its thirty-seventh session, in its resolution 37/90 of 10 December 1982, the General Assembly endorsed the recommendations of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE 82) and decided that the United Nations Programme on Space Applications should promote the dissemination of information on advanced space applications and new systems developments among managers and decision-makers, particularly for the benefit of the developing countries. At its thirty-third session, in June 1990, the Committee on the Peaceful Uses of Outer Space endorsed the United Nations Programme on Space Applications.

2. The United Nations/Economic and Social Commission for Asia and the Pacific (ESCAP)/Office of the United Nations Disaster Relief Coordinator (UNDRO) Workshop on the Applications of Space Techniques to Combat Natural Disasters was one of the activities of the Programme for 1991 as proposed by the Expert on Space Applications and recommended subsequently by the Scientific and Technical Subcommittee at its twenty-eighth session. The General Assembly, at its forty-fifth session, endorsed the activities of the Programme on Space Applications for 1991 (resolution 45/72). The Workshop was co-sponsored by the Government of China and hosted by the State Science and Technology Commission (SSTC) at Beijing from 23 to 27 September for the benefit of participants from the ESCAP region.

3. The objective of the workshop was to consider ways in which developing countries of the ESCAP region could use space techniques such as remote sensing, satellite meteorology, satellite telecommunication and satellite positioning systems to combat the rapid onset of natural disasters such as forest fires, floods, storms, winds, cyclones, earthquakes and volcanic eruptions. The workshop also discussed the need to develop ground systems and database management applications (including the use of Geographic Information Systems (GIS)) for monitoring these natural disasters as well as slow onset disasters such as desertification, erosion processes and impact of atmospheric changes.

4. The present report, which covers the background, objective, organization, observations and recommendations of the workshop as well as a summary of the lectures presented, has been prepared for the Committee on the Peaceful Uses of Outer Space and its Scientific and Technical Subcommittee. Participants will report to the appropriate authorities in their respective countries.

B. Organization and programme

5. Invitations to participate in the workshop were sent by the United Nations to professionals with responsibilities for disaster prevention and relief in their respective countries or those directly involved in such

activities as a result of the work programmes of their institutions. The workshop was attended by 72 participants from the following Member States and organizations: Bangladesh, China, France, Indonesia, Japan, Lao People's Democratic Republic, Malaysia, Mongolia, Myanmar, Philippines, Sri Lanka, Thailand, United States of America, the European Space Agency (ESA), International Maritime Organization (IMO), ESCAP, Food and Agriculture Organization of the United Nations (FAO), United Nations Educational, Scientific and Cultural Organization (UNESCO), UNDRO and the United Nations (Outer Space Affairs Division).

6. Funds allocated by the ESCAP, UNDRO and the United Nations for the organization of the workshop were used to defray the cost of international air travel and incidental expenses of 17 participants. The Government of China, through SSTC, provided the workshop facilities, room and board for 17 participants and local transportation for the duration of the workshop and will be publishing the proceedings of the workshop.

7. Welcoming and keynote addresses were presented by Prof. Hui Yongzheng, Vice Chairman of the State Science and Technology Commission of China, Dr. Li Zengyi, Department of Disaster Relief, Ministry of Civil Affairs and Prof. Ma Junru, Director of the National Remote Sensing Centre, on behalf of the Government of China; Dr. He Changchui, Project Manager/Coordinator, Regional Remote Sensing Programme, on behalf of ESCAP; Mr. R. Garcia, Deputy Resident Representative, on behalf of the United Nations Development Programme (UNDP) Field Office in Beijing; Dr. J. C. Scott, President, Centre for Public Service Communications, on behalf of UNDRO; and Dr. A. A. Abiodun, Expert on Space Applications, on behalf of the United Nations.

8. The programme of the workshop (see the annex to the present report) was developed by the United Nations in consultation with ESCAP. The workshop was conducted through a number of plenary and working group sessions. At the latter, the participants discussed the issues associated with disaster preparedness and mitigation as well as the observations that follow.

C. Observations and recommendations of the Workshop

1. Causes of disasters

9. The critical factors that distinguish natural phenomenon from natural disasters are loss of life and property. Certainly, humans cannot prevent the occurrence of natural phenomenon, such as typhoons, hurricanes, earthquakes and volcanic eruptions - however, their disastrous effects can be lessened significantly if well conceived disaster response plans and mitigation strategies are in place prior to their occurrence.

10. As an example, deforestation caused by overlogging of indigenous trees which assist in the percolation of rainwater into the soil substrata often reduce the spongy nature of the soil, that is the ability of the soil to retain water. Thus, deforestation often results in flooding, and soil erosion

and landslides, the last two being the main causes of siltation of irrigation and hydroelectric programmes downstream and the tearing up of farmlands.

11. Misuse of the land such as (a) farming and building on steep slopes that are susceptible to landslides (b) establishment of human settlements within areas of volcanic activity, in earthquake zones and in flood plains and (c) the building of reservoirs in earthquake zones, often lead to great property loss and human suffering. Thus, many of what humans describe today as natural disasters are generally human-induced and their impact is often magnified and intensified by environment mismanagement.

2. Use of current and future space systems in disaster planning, mitigation, preparedness and relief

12. There are many uses of space systems in disaster mitigation. In considering the uses, it is important to distinguish among three types of systems: operational, experimental and future. These systems could also be categorized according to applications: Communications, Meteorology and Earth sciences. The latter categories are represented by low- and high-spatial resolution Earth observation systems. In addition, there are special geophysical satellites of importance in disaster management: satellite systems which can be used to determine the positions of Earth-based beacons or receivers, such as, Global Positioning Satellite system (GPS). All of these can be used in the pursuit of the various elements of disaster management.

(a) Disaster prevention

13. As population pressure grows due to increases or shifts in population density, increased strain is placed on the land; and humanity takes increasing chances with nature. Houses, utilities, schools and roads are placed in jeopardy of earthquakes, flooding, landslides and many other types of hazards. An important future capability for flood and landslide hazard assessment will be the digital topographic map derived at high spatial resolution by specialized satellites.

(b) Disaster preparedness and warning

14. Because of their repetitive synoptic coverage, satellites are perhaps most effective in providing essential information leading to effective disaster warnings. Archetypes of this capability are the meteorological satellites, especially geosynchronous satellites used for tracking severe storms and weather patterns. Although there are operational systems currently in use, they have limited capability. Some of the existing as well as future experimental systems permit important sea surface wind determinations, which should improve forecasting capabilities. These capabilities are, of course, related to the ability to warn of deadly storm surges. The latter is an example of one of the many areas in which theoretical and experimental space research activities are needed in order to improve our understanding of a hazardous phenomenon.

15. Meteorological satellites are also used to warn of impending disasters on land. Relatively low-resolution operational instruments provide valuable data for indirectly estimating rainfall, possible drought and locust infestations. Future satellites will provide the exciting capability to measure rainfall directly. Such data may be of use in flood forecasting and landslide warning. Experiments are currently being conducted to determine the validity of using these satellites for predicting earthquakes and forecasting volcanic eruptions.

16. Precise positioning measurements with the aid of GPS satellites can be used to measure the accumulation of regional strain, which may be a precursor to an earthquake. However, such applications are still in the research stage, as are concepts for studying thermal anomalies as earthquake precursors.

(c) Disaster relief

17. Normal ground-based communication links are very often wiped out during a disaster; accordingly, satellite-based communications can be very important. This importance has assumed even greater importance with the advent of mobile capability for voice (standard A) and data link (standard C) communications. During the relief period, such equipment can be used to transmit relief requirements and to provide medical advice to under-trained or overworked personnel on site. Such capabilities are now operational.

(d) Disaster assessment and reconstruction

18. Disaster assessment generally places exceptional requirements on a satellite system: it must respond very quickly. Optical sensor systems cannot guarantee the availability of images of a flooded area because such areas are likely to be cloud-covered immediately after a flood. The launch of research satellites with synthetic aperture radar (SAR) in the recent past, and their attainment of operational status in the near future, will alleviate such problems. The recent eruption of Mt. Pinatubo in the Philippines has demonstrated that the frequencies of Earth observation by satellite can provide useful information on volcanic ash fall cover. Similar studies have also shown that such data can be useful in observing forest damage due to severe storms.

Recommendations

19. One key to avoiding such disasters is hazard assessment, most often in the form of a vulnerability map. Perhaps the most important component of the vulnerability map which space technology can provide is the land use or land cover map. These can show the location of cultural concentrations, such as houses, relative to earthquake zones (seen as lineaments), flood plains and landslide hazard areas. Such data are available operationally through Landsat and Spot programmes. Because of the resources needed to use these data, it is important for the users to know whether the operators of a space segment are committed to providing the data on a continued operational basis.

(e) Communication systems for disaster mitigation

20. Traditional terrestrial telecommunications - particularly in remote areas of disaster-prone countries - have been costly to install, difficult to repair and vulnerable. Accordingly, such systems have been virtually useless in areas where geography or climate inhibited their installation and maintenance, and thus have been of limited value to disaster managers. Fixed Satellite Services provide a variety of applications for disaster management but they, too, have limitations. Because of their need for large-size receiving and transmitting antennas (and associated high-power requirements), quick response to areas of the world that are difficult to access remains a significant limitation to effective disaster response. However, with recent developments of Very Small Aperture Terminals (VSATs), Ultra Small Aperture Terminals (USATs), and phased array antennas, Fixed Satellite Service will likely be of greater use in disaster management.

21. One of the most recent and dynamic communications technologies available to disaster managers is mobile service by satellites. This low-cost communication capability has proved, even in the relatively short time of its commercial availability, that it can offer dramatic results in relief efforts which have not been possible before. Furthermore, as a complement to remote sensing technology, mobile service has the capability to dramatically improve risk assessment, disaster preparedness, early warning and onset and post-disaster relief operations. This service is now available to areas previously considered inaccessible because of their location, terrain, weather or demography.

22. Although various international institutions and individual countries have filed, or indicated their intention to file, for mobile satellite orbital slots, these services will likely be available only on a national or regional basis. However, it is not certain that they will be inter-operable, that is, they may not be able to operate at the same frequencies, thus limiting communication between and among systems.

23. There is, however, a mobile satellite service that is currently available throughout the world and is operated by the International Maritime Satellite Organization (INMARSAT). The participants recognized the commitment of INMARSAT to develop services that are responsive to the needs of the disaster management community, further recognized INMARSAT's generosity in granting a free space segment during catastrophic disasters and noted the additional support of many signatory countries that have offered free use of their coastal Earth stations. The need to incorporate this type of communications resource into disaster planning and response was recognized by the participants. Additional needs were also discussed, as described below.

24. On a national level, the need exists to reduce the vulnerability of existing telecommunications systems; to ensure that future terrestrial and fixed satellite infrastructure is planned and constructed taking into account the particular types of disasters that are common to that country; and to augment these systems with portable, easy-to-operate mobile satellite equipment.

25. From the international point of view, countries respond to human needs that arise from catastrophic disasters. Addressing these needs on an international level requires the development of agreements that would facilitate such international response efforts and the entry and exit as well as the operation of communications equipment by relief workers in affected areas. In this respect, UNDRO's current initiative for facilitating international consideration of a formal convention on disaster communications was recognized.

3. Factors influencing effective use of space techniques

26. These factors include:

(a) Capability and availability of technology;

(b) Affordability of technology, relative to the intended application and other possible options that might accomplish similar objectives;

(c) National and international regulations that encourage or inhibit effective applications of technologies;

(d) Institutional relationships and protocols required to facilitate optimal use of technologies by all users;

(e) National and international political issues that may have a negative impact on the acquisition and application of technology;

(f) The requirement to include disaster management experts in the process of planning for technology development and application;

(g) The need to develop training programmes in the application of existing technologies and education programmes that could lead to the development of indigenous capability and frequent applications of technologies;

(h) The need to undertake and support research in the development of ground systems and data management applications, including GIS, as a complement to development of space hardware.

27. The workshop also noted that FAO had made considerable advances in the operational use of satellite remote sensing techniques for monitoring key environmental parameters, such as precipitation and vegetation biomass cover, which are relevant to disaster prevention in relation to droughts, flooding, insect pests and longer-term environmental degradation. Furthermore, the meeting noted that FAO, in close cooperation with the European Space Agency, was developing satellite communication capabilities which in the near future could provide an effective means for large-volume data and information exchange on a real-time basis at a regional level.

28. GIS is a very powerful tool for the handling of remote sensing data and for the overlaying of such data with other types of digitized thematic information such as topographic, geologic, vegetation and population density maps. The development of very powerful PC-based and user-friendly GISs has facilitated image processing and geometric and scale correction procedures which are necessary for the production of different layers of precisely matching maps.

29. Current developments threaten to cause a "knowledge gap" between those who can use remote sensing and GIS and those who cannot. The gap is more apparent between older and younger professionals than it is between developing and industrialized countries. The application of remote sensing techniques and GIS can lead to the best possible results only when used by specialists with a great amount of conventional experience in the field of applications, such as meteorologists and earth scientists; these specialists are able to bring their wealth of experience to bear on the analysis being made.

Recommendations

30. In order to improve national and regional forecasting capabilities for environmental monitoring, with specific reference to drought and flood forecasting, it is recommended that the countries of the ESCAP region, as much as possible through the mechanisms of the ESCAP Regional Remote Sensing Programme, work closely with FAO for the transfer of ARTEMIS and DIANA technology to the region, taking into account the existing facilities for satellite data acquisition and processing.

31. Remote sensing and GIS should not only be taught at the university level, but should also be introduced into the curricula of short-term training courses for mid-career professionals. In this connection, training packages should be developed for hands-on experience in the collection and management of remote sensing and Geographic Information Systems.

4. Combating disasters in the ESCAP region

(a) Observations

32. The Workshop noted that the ESCAP region is very prone to disasters. Among these were the catastrophic cyclone and tidal surges that hit Bangladesh in May, the Mt. Pinatubo volcanic eruption in the Philippines in June and the devastating floods in China in July, just to name a few that have already occurred during 1991. Atmospheric phenomena such as typhoons and tropical cyclones, geological phenomena such as earthquakes, and volcanic eruptions are of great concern in the ESCAP region.

33. Many countries of the region have come to appreciate the growing importance of using space technology to combat natural disasters with the aid of satellite systems such as ALMAZ, ERS-1, INSAT, METEOR, METEOSAT, MOS, LANDSAT, SPOT, NOAA, GMS and GPS; these systems are used in conjunction with

ground-based and serial systems. However, a number of limiting factors, including the cost of data, hinder the full utilization of these capabilities.

(b) Recommendations emanating from lessons learned

34. It was recommended that Member States address themselves to the following needs:

(1) In-depth education and research;

(2) Early dissemination of warning;

(3) Establishment of policies against illegal logging and adoption of rational logging policies;

(4) Coastal zone monitoring;

(5) Constant monitoring of forest fires;

(6) Gaining the confidence of the public through accurate weather forecasting;

(7) Regular weather information over the airwaves and on site;

(8) Building of dykes and other structures to control lava flow from volcanic eruptions;

(9) Use of GPS system for detecting frequent motions of tectonic plates.

5. Essential national steps, and mechanisms for promoting regional and international cooperation

(a) National

35. The essential steps and mechanisms at the national level include:

(1) Updating of equipment for data reception and disaster warning systems;

(2) Establishment of contact points in each country for disaster mitigation purposes and for the inventory of telecommunications and remote sensing facilities that may be available for disaster management;

(3) Formulation of disaster mitigation policies and development of programmes of action, including coordination of activities with relevant national entities;

(4) Re-establishment of communication links which should be more resilient and better able to withstand future disasters.

36. Until recently, mobilization for preparedness has been largely a public sector affair with local authorities bearing the burden of plan formulation, financing and strategy execution. But pre-disaster plans can only be effective if disaster-prone countries are able to incorporate such plans into their programmes and implement them as part of a regular institutional process. National and community capabilities are limited, particularly in the developing countries, where the capacities of the national infrastructure are often strained to manage even the most basic of social and economic development programmes.

37. In order to reduce this reliance on an overtaxed public-sector competence, and recognizing the need to generate local capacity to prevent and prepare for disasters, more attention should be given to attracting into prevention, mitigation and preparedness planning and operations entities outside the government structure such as local businesses, trade groups, voluntary organizations and community leaders. The business community in particular, with its financial, technological and logistical capabilities, should be regarded as a valuable partner in the planning process and a resource which should not be ignored.

(b) Regional

38. At the regional level the workshop noted the need for:

(1) Exchange of information within the ESCAP region;

(2) Joint active management of river basins among Member States that share the same catchment with a view to prevent and mitigate potential disasters;

(3) Establishment of regional understandings for development of strong relationships between regional communication communities and disaster communities. In this connection, the use of regional communication systems (e.g. Palapa and Asia-Sat) to share programmes and information should be fully encouraged;

(4) Continuation of the current mandatory practice of distributing processed data from its GMS meteorological satellite by Japan.

39. The workshop noted the catalytic and direct role of the ESCAP/UNDP Regional Remote Sensing Programme (RRSP) in promoting remote sensing development and applications in the ESCAP region. The workshop recommended that ESCAP/UNDP RRSP should continue to provide technical assistance to its member countries, through its established networks, with emphasis on organizing training and education activities, pilot projects and information services, including the use of remote sensing technology to combat natural disasters.

(c) International

40. The workshop noted that at present, there is no globally coordinated observational satellite system that could provide daily observations for coping with fast transient environmental phenomena. The workshop also noted that in this connection the Society of Japanese Aerospace Companies (SJAC) is proposing the development of such a system, to be known as the World Environment and Disaster and Observation Satellite System (WEDOS), in collaboration with the Government of Japan and other space agencies around the world. WEDOS is a constellation of 38 combined polar and geostationary satellites. SJAC hopes that WEDOS could eventually be an effective and realistic disaster mitigating space system, and that it could be developed and managed through the United Nations.

SUMMARY OF PRESENTATIONS

A. Overview of satellite technology usage in disaster management

41. Over recent years a number of major disasters - of natural, technological or ecological origin - have made the international community dramatically aware of the immense loss of human life and economic resources caused regularly by such calamities. Based on the recognition of the devastating impact of disasters on socio-economic systems as a whole, with the beginning of the 1990s the international community has embarked on a major, visionary initiative, the International Decade for Natural Disaster Reduction (IDNDR).

42. With regard to space technology, IDNDR does more than simply educate the disaster management community in the simple uses of the technology. It promotes a recognition that the national infrastructures that make possible these applications must be encouraged and supported in their mission and adequately protected against disasters themselves. Disaster prevention, preparedness and relief operations can benefit from existing as well as new space technologies.

43. Satellite technology can make substantial contributions in each of the three phases of disaster management: preparedness, prevention and relief. Various kinds of satellites, especially communications, meteorology, remote sensing and geophysical satellites, are or may become useful tools in the above phases. Though much of this technological capacity has been in existence for more than a decade, operational capabilities are currently provided only for storm warnings and search-and-rescue activities.

44. Since the forecasting of natural hazards relies on either mathematical models or the empirical understanding of physical phenomena, the ability to improve, update and build on these observations is critical. New knowledge gained over the past decade is fundamentally changing the way we perceive the Earth and its components. Recent space science technology has also created a dramatic leap in the ability to measure and learn about the physical, chemical

and biological interactions of the Earth's magnetosphere, atmosphere, oceans and land areas and to assess the importance of these interactions to global, physical and biogeochemical processes.

45. The main aspects to be considered in natural disaster mitigation are: (a) accurate prediction of the event that may cause or contribute to the cause of a disaster; and (b) a rapid assessment of the location and extent of damage and an evaluation of the potential for further damage (such as earthquake aftershock, mud slides, storm surges).

46. Improvement in prediction must be based mainly on an improved knowledge of the causes and mechanisms of a disaster (e.g., improvement of meteorological forecasting, medium- and long-term climate changes, plate motion as driving mechanism for earthquake and volcanic activity), while evaluation of disasters must be based on the improvement of Earth observation systems, which must become more independent of weather and sunlight conditions.

47. However, weather forecasting nowadays is severely limited by the lack of accurate information on wind and wave speed and direction over a large part of the ocean, mainly in the southern hemisphere. Also, the lack of precise altimetric and geodetic measurements over long periods is a constraint to plate motion models development on a human time scale. A large part of the rain forest over the Earth's surface is poorly mapped and deforestation of those areas can scarcely be measured by conventional systems. Disasters caused by rainstorms and flooding are difficultly measurable with conventional optical sensors.

B. Communications satellites and disaster mitigation

48. Satellite communication systems offer an important potential for real-time dissemination of disaster information. Early warning and quick re-establishment of communications are vital to mitigation and relief operations for all rapid-onset hazards, such as earthquakes, floods, landslides, hurricanes, tsunamis, volcanic eruptions and wildfires. When natural disasters strike, the survival of the local population may well depend upon the contingency planning and preparation that is already in place, as relief may be hours or days in arriving. All too often, local telecommunications networks are destroyed by disasters. When this happens, it is not likely that vital services can be reconstituted in the crucial early hours of the response phase.

49. There are satellite solutions which can provide reliable, instantaneous and simple-to-use communication with the outside world. New low-cost mobile communications by satellite can play a major role in reducing the devastating effects of natural disasters and will complement and enhance existing terrestrial and fixed satellite services. They dramatically improve hazard prediction, risk assessment, disaster preparedness, early warning and onset and post-disaster relief operations. This service is now available to areas previously considered impractical or impossible to cover because of their location, terrain, weather or demography.

50. Mobile satellite communications can be used by land, aeronautical and maritime transportation industries, so that disruption of distribution networks of food, water and essential medicaments due to disasters will be reduced. This also should enable a reduction in response time to medical emergencies and enhance the ability to stabilize patients "on the scene". Further, epidemiological information, disease registries and blood bank and medicine inventories could be communicated more rapidly.

C. Meteorological satellites

51. Meteorological satellites can continuously monitor the atmosphere from space. Cloud maps, atmospheric temperature, humidity, wind, radiation, precipitation distribution and other information derived from a meteorological satellite's payload have the advantage of simplicity.

52. Synoptic observations of meteorological satellites of regional cloud distribution, nearly in real time from geosynchronous orbit, have become an important element in weather forecasting. Advanced techniques for determining cloud-top heights and wind fields are less well known but at least as important. Several types of polar-orbiting meteorological satellites have also been launched. As in the case of geosynchronous satellites, these are expected to be a continuous source of environmental data and should be considered operational.

D. Remote-sensing satellites

53. Remote-sensing satellites are used to observe, map and monitor features and phenomena on the Earth's surface. They are distinguished from meteorological satellites by their finer spatial resolution capability. Such satellites orbit the Earth around its poles. For technical reasons (e.g., limitations on the rate at which data can be transmitted to Earth), these satellites' total field of view is limited to a swath several hundred kilometres wide, thus limiting the amount of the globe they can observe in a day. Such satellites are of potential interest and use to the disaster-mitigation community.

54. Considering the potential of remote-sensing systems for disaster management application, it is important to realize their restrictions. Three parameters of such systems which are ultimately related are the spatial, radiometric and spectral resolution. If the spatial resolution is improved, the radiometric and spectral resolution will be decreased. The spectral resolution can be improved by lowering the orbit of the spacecraft, thus decreasing the width of the swath. This results in lower frequency of observation.

55. Frequency of observation, a critical factor in terms of sudden disasters, may be considered as the satellite's "temporal resolution". The rigidity of orbital mechanics and optical system costs place considerable constraints upon

the most desirable spacecraft characteristics for response to sudden disasters: radiometric, spatial and temporal resolution. For the time being, the optimal instrument appears to be a pointable imager that sacrifices spectral capability for spatial (and/or temporal) resolution. Some improvements would be achieved by flying such an instrument in a low-inclination orbit.

56. Another important factor to be considered is cloud cover, which is responsible for the loss of approximately half the opportunities for observing the Earth. Instruments sensitive to microwaves can avoid this problem owing to the fact that they can penetrate through clouds. While their capacity for spectral discrimination is limited, they can obtain good radiometric resolution. High spatial resolution may be achieved using the synthetic aperture technique, which involves correlating the signal from several points along the spacecraft's orbit.

E. Existing systems

57. Today, the Earth is encircled at the equator by a set of geostationary meteorological satellites and low-altitude polar-orbiting satellites. Further, geosynchronous communication satellite systems serve various national and regional needs throughout the world. Only two of the remote-sensing satellite systems can currently be considered operational from the point of view of sufficiently quick response: LANDSAT and SPOT.

58. The INMARSAT global mobile satellite communications system is ideally suited to supporting disaster preparedness and relief operations throughout the world. The system provides high-quality, reliable communications services through small, highly mobile terminal equipment. The INMARSAT system matches the specifications for a disaster communications network: it is independent of local telecommunications infrastructures, is not prone to single point failure, provides unlimited communications, is compatible with other INMARSAT users, simple to operate, flexible, portable and reliable.

59. Another international satellite system for search and rescue consisting of a constellation of polar-orbiting satellites and a network of Earth stations is COSPAS-SARSAT. It provides distress alert and location information to appropriate rescue authorities anywhere in the world for maritime, aviation and land users in distress. Monitoring the Doppler shift in reception from a transmitting distress beacon as the satellite passes over the beacon allows rescue teams to obtain a directional reference on the beacon's location. Another satellite passing from a different direction can provide another directional reference at the intersection of the vectors.

60. Launched successfully by the European Space Agency on 17 July 1991 into a polar orbit with mean altitude of 780 km, the Earth Resources Satellite ERS-1 represents a new generation of remote-sensing satellites. It uses advanced active microwave techniques to make global measurements and imaging regardless of cloud and sunlight conditions. It also measures many parameters not

covered by existing remote-sensing satellite systems (LANDSAT, SPOT, ALMAZ, PRIRODA), including those of sea state, sea surface winds, ocean circulation, sea and ocean levels, as well as all-weather imaging of ocean, ice and land. Data will be collected from remote areas such as the polar regions and the southern oceans, from which there has been no information so far.

61. To implement these tasks, ERS-1 carries on board a set of active microwave sensors which allow collection at all weather conditions of global geophysical information over the oceans as well as high-resolution imaging of coastal and land areas. The ERS-1 mission will provide data contributing to (a) improved understanding of ocean-atmosphere interaction in climate models; (b) major advances in our knowledge of ocean circulation and the transfer of energy; (c) more reliable estimates of the mass balance of ocean ice sheets; (d) better monitoring of dynamic coastal processes and pollution; and (e) improved detection and management of the land-use changes and cover.

F. Future systems

62. A concept of the World Environment and Disaster Observation System (WEDOS) using a space segment has been proposed by the Society of Japanese Aerospace Companies in collaboration with the Government of Japan. The purpose of this system is to implement global-scale around-the-clock monitoring of the Earth environment and observation of natural disasters by the space segment consisting of 26 Earth observation satellites to be launched into medium-altitude orbit.

G. Application of satellite technology to combat natural disasters - case histories

63. Floods, cyclones and other disasters are common phenomena in Bangladesh every year. Following upon the catastrophic floods of 1987 and 1988 and the severe cyclone of April 1991, the Government of Bangladesh has sought anew to improve its disaster management. Since almost all the rivers of Bangladesh have their headwaters outside the country, regional cooperation and exchange of hydrometeorological data among the neighbouring countries are of extreme importance for an improved disaster preparedness programme.

64. In November 1988, heavy rains and devastating floods occurred in southern Thailand, causing an estimated damage of about US$ 300 million and the loss of more than 400 human lives. GMS-3 satellite images were used to indicate heavy rain areas. Two days before the events and two days afterwards data sets from LANDSAT and SPOT satellites were selected to analyse flood damage. Based on the analysis, 3 per cent of the forest area was converted to agricultural use, especially for rubber plantations or orchards, and 11 per cent of the area was registered as having experienced landslides. The outcome of the analysis showed that satellite image data can produce satisfactory results for land usage determination.

65. Earthquakes are the result of rapid failure and release of energy resulting from strain in the lithosphere. In the face of a large break in the lithosphere various kinds of material movement, whether resulting from mechanical or physical-chemical action, will lead in the final analysis to increase in thermal energy. Therefore, surveying the variation of the ground temperature in time and space using the satellite thermal infrared waveband is a feasible, fast and relatively accurate way to detect the precursor of the impending earthquake.

66. A comparison of currently existing earthquake prediction techniques and those applied in studies of seismic monitoring and prediction reveals a unique superiority of the remote sensing technology, in that it can macroscopically monitor the dynamic evolution of the thermal anomaly on the Earth's surface and improve accuracy of earthquake prediction. Its shortcoming lies in the fact that the Advanced Very High Resolution Radiometer (AVHRR) and the Visible-Light Thermal Infrared Spin Scanning Radiometer carried by today's meteosatellites are unable to make their observations through cloud layers, so that temperature on the ground cannot be measured. However, it is possible to estimate the temperature condition under the cloud layer by combining the analysis of the temperature value of the air on the ground at the meteorological stations with the satellite remote sensing data.

67. Airborne and satellite remote sensing techniques, such as photography, imaging radar and multispectral scanning, provide imagery of the Earth's surface which is a valuable tool for the inventory and monitoring of mountain hazard phenomena. With computer-based Geographic Information Systems (GIS) it is possible to process spatially distributed data of a geographic nature and to use information derived by digital processing and visual interpretation of remote sensing imagery. A GIS enables the analysis of the influence of a large number of terrain factors on the occurrence of mountain hazard processes.

68. The application of both currently available and future satellite remote sensing is limited, however, by its spatial resolution, which does not allow for the identification of landslide features smaller than 100 m in conditions of high contrast between the features to be mapped and the surrounding background. If contrast conditions are less favourable, identification is even more limited, to features larger than an order of magnitude of 400 m. The need for stereo imagery, which is necessary to recognize landforms in stereoscopic vision, enhances the applicability of currently available SPOT imagery.

69. Since 1976, the FAO Remote Sensing Centre, in cooperation with relevant FAO user divisions, has been actively developing and testing the operational use of data from environmental and Earth resources satellites to improve the information bases of the FAO Global Information and Early Warning System (GIEWS) on the Food and Agriculture and Desert Locust Plague Prevention Programme at international, regional and national levels.

70. The operational satellite environmental monitoring system ARTEMIS, implemented by FAO and its cooperation for real/near real-time precipitation

and vegetation assessment in Africa, the Near East and South-West Asia, was designed and implemented based on the integrated use of high-frequency Meteosat and NOAA AVHRR data. The DIANA satellite telecommunication system will permit near real-time transmission of high-volume ARTEMIS digital data products to microcomputer-based terminals of users at both regional and national levels in Africa.

Annex

PROGRAMME OF THE WORKSHOP

Date	Time	Subject	Speaker
Monday, 23 September	9-9.45 a.m.	Opening ceremony	Y. Hui (China) C. He (ESCAP) R. Garcia (UNDP) Z. Li (China) A. Abiodun (United Nations)
	10-10.30 a.m.	Keynote address: Disaster risk assessment and preparedness in China	Prof. J. Ma (China)
	10.30-11 a.m.	Keynote address: The role of space applications in the International Decade for Natural Disaster Reduction	J. C. Scott (UNDRO)
	11-11.15 a.m.	Break	
		Infrastructure: communications, remote sensing and data collection satellites	
	11.15-11.45 a.m.	ERS-1 and its possible roles in disaster mitigation	Solé (ESA)
	Noon-2 p.m.	Lunch	
	2-2.45 p.m.	Plan of the World Environment and Disaster Observation Satellite System	T. Kuroda, S. Koizumi (Japan)
	2.45-3.30 p.m.	Use of INMARSAT in disaster relief operations	J. C. Bell (INMARSAT)
	3.30-3.45 p.m.	Break	
	3.45-4.30 p.m.	Satellite-based search and rescue	P. H. Pisani (France)
	4.30-5 p.m.	Practical use of satellite terminals for disaster relief operations and the establishment of such facilities at the national level	J. C. Scott (UNDRO)

Date	Time	Subject	Speaker
		Applications to disaster prevention and relief	
Tuesday, 24 September	9.45 a.m.	Uses of satellite technology in disaster management	L. S. Walter (United States)
	9.45-10.30 a.m.	Applications of meteorological satellite data in weather forecasting and disaster monitoring in China	X. Xiang, C. Tian (China)
	10.30-10.45 a.m.	Break	
	10.45-11.30 a.m.	Advanced warning and evaluation of damage caused by cyclones, floods and other meteorological phenomena in Bangladesh	Md. A. Rahman, S. Begum (Bangladesh)
	11.30 a.m.-12.15 p.m.	"Mountain hazard mapping in the Andean environment: a UNESCO-sponsored project using remote sensing imagery and the ILWIS PC-based Geographic Information System"	N. Rengers (UNESCO)
	Noon-2 p.m.	Lunch	
	2-2.45 p.m.	Drought preparedness monitoring and mapping for peninsular Malaysia	M. Baharuddin, M. Hashim (Malaysia)
	2.45-3.30 p.m.	Operational environmental satellite remote sensing for food security and locust control by FAO, the ARTEMIS and DIANA systems	J. U. Hielkema (FAO)
	3.30-3.45 p.m.	Break	
	3.45-4.30 p.m.	The flood control remote sensing information system and its applications in China	C. S. Hu (China)
	4.30-5.15 p.m.	Flood disaster and assessment at Nakhon Si Thammarat province in November 1988	C. Yusabye, S. Polngam (Thailand)
Wednesday, 25 September		Visit of disaster prevention and relief facilities	China
	9-11.30 a.m.	Remote Sensing Centre, Ministry of water resources	
	1.30-5 p.m.	Group 1	
		Chinese Academy of Sciences: Institute of Geography, Institute of Remote Sensing Applications	

Date	Time	Subject	Speaker
Wednesday, 25 September (continued)		Group 2 Satellite Meteorology Centre, State Meteorological Administration	
Thursday, 26 September	9-9.45 a.m.	Research on monitoring and prediction of impending earthquakes using satellite remote sensing techniques	Q. Zuji, X. Xiudeng, D. Changgong (China)
	9.45-10.15 a.m.	Regional cooperation on remote sensing technology applications to natural disaster monitoring and prevention	C. He (ESCAP)
	10.15-11 a.m.	Development of indigenous capability in space science and technology	A. A. Abiodun (United Nations)
	11 a.m.-12.30 p.m.	Working group sessions	
	12.30-2 p.m.	Lunch	
	2-5 p.m.	Working group sessions	
Friday, 27 September	9 a.m.-Noon	Working group sessions	
	Noon-12.30 p.m.	Closing ceremony	

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COMMITTEE ON THE PEACEFUL USES OF
OUTER SPACE

REPORT ON THE THIRD UNITED NATIONS INTERNATIONAL TRAINING COURSE ON REMOTE-SENSING APPLICATIONS TO GEOLOGICAL SCIENCES, CO-SPONSORED BY THE CARL DUISBERG SOCIETY BERLIN AND THE EUROPEAN SPACE AGENCY IN COOPERATION WITH THE GOVERNMENT OF GERMANY

(Potsdam and Berlin, Germany, 7-25 October 1991)

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INTRODUCTION

A. Background and purpose of the course

1. The General Assembly, at its thirty-seventh session, adopted resolution 37/90 of 10 December 1982, endorsing the recommendations of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE 82) that the United Nations Programme on Space Applications should promote the growth of indigenous nuclei and an autonomous technological base in space technology at the local level. At its thirty-third session, in June 1990, the Committee on the Peaceful Uses of Outer Space endorsed the United Nations Programme on Space Applications for 1991 as recommended by the Scientific and Technical Subcommittee of the Committee at its twenty-eighth session. Subsequently, the General Assembly, at its forty-fifth session, endorsed the activities of the Programme on Space Applications for 1991 (resolution 45/72).

2. The third United Nations International Training Course on Remote-Sensing Applications to Geological Sciences was part of the 1991 activities of the United Nations Space Applications Programme. The training course was co-sponsored by the Carl Duisberg Society Berlin and the European Space Agency (ESA), organized in cooperation with the Government of Germany and hosted by the Central Institute for Physics of the Earth Potsdam and the Free University of Berlin, Germany, from 7 to 25 October 1991.

3. The objective of the training course was to provide education and practical training to participants from developing countries and Eastern European countries with respect to techniques, methods and results of recent applications of airborne and satellite remote sensing to geological sciences. The following topics were covered by the programme of the training course:

(a) Fundamentals of remote sensing including analog-optical and digital image processing, classification procedures, geostatistics, analysis of geological units, lineament analysis and field checking;

(b) Geological fieldwork in two units of the Central European Hercynides (Harz Mountains and the Vogtland block) in the eastern part of Germany, carried out in areas of different geological structures (basement, cover rocks) under humid climate;

(c) Practical work in data classification by means of aerial photographs and satellite images, controls of mapped remote-sensing features, training in data collection of spectral behaviour of rock and soil units and its interpretation;

(d) Interpretation and development of geological models.

4. The present report, which covers the background, objectives and organization of the training course, as well as a summary of presentations, has been prepared for the Committee on the Peaceful Uses of Outer Space and its Scientific and Technical Subcommittee. Participants in the training course will report to appropriate authorities of the Government, universities and research institutes in their respective countries.

5. Participants expressed their appreciation to the United Nations and to the Government of Germany for organizing and hosting the course, for their financial assistance and for the scientific and technical quality of the training course.

B. Organization of the course

6. Invitations to nominate participants for the International Training Course were sent by the United Nations to developing countries and Eastern European countries. The course was attended by 19 participants from the following countries: Bangladesh, China, Czechoslovakia, Ghana, Hungary, India, Jordan, Mongolia, Pakistan, Philippines, Poland, Romania, Sudan, Syrian Arab Republic, Thailand, Viet Nam, Yemen and Zimbabwe. The participants were scientific and technical personnel actively engaged in geology and remote sensing in their respective countries.

7. Instruction for practical work and lectures were provided by experts from Finland, Germany, Italy, the Netherlands, the Union of Soviet Socialist Republics and the European Space Agency.

8. The Carl Duisberg Society Berlin, the Central Institute for Physics of the Earth Potsdam and the Institute for Geology, Geophysics and Geoinformatics of the Free University of Berlin coordinated the local arrangements and provided the technical equipment, materials, course facilities and local transportation.

9. Funds allocated by the United Nations and the European Space Agency were used to cover the cost of international travel for 19 participants. The Government of Germany, through the Carl Duisberg Society, Berlin, provided fellowship to cover subsistence and course fees for those participants.

10. Welcoming addresses were presented by Mr. B. Schleich, on behalf of the Carl Duisberg Society Berlin, by Mr. W. Schunack, on behalf of the Free University of Berlin, by Mr. E. Hurtig, on behalf of the Central Institute for Physics of the Earth Potsdam, and by Mr. H. J. Haubold, on behalf of the United Nations.

11. The training course consisted of a series of integrated lectures, presentations of case studies, exercises and field trips to different geological areas in the eastern part of Germany. The proceedings of the training course will be published in the Berliner Geowissenschaftliche Abhandlungen of the Free University of Berlin, Germany.

SUMMARY OF THE COURSE

A. Introduction to remote-sensing interpretation for geological sciences

12. Satellite remote sensing is especially useful for applications to survey tasks which do not require too much direct ground information; in other cases, the use of airborne or ground-based observations provides more detailed information. Satellite remote sensing is well suited for geological reconnaissance surveys, especially in arid and semi-arid areas.

13. Satellite images contain integrated information on such features as vegetation, soil, rocks, land forms, drainage patterns and geologic structures. Thematic interpretation of these complex patterns of forms, shades, colours, structures, textures and their mutual relationships requires, besides some background about the physical fundamentals and peculiarities of remote-sensing data, a thorough understanding of the processes of relief formation and their dependence on climate, the relationships between relief, rock types and geological structures, between the interaction of endogenous and exogenous Earth-shaping forces, between the scale of features and their possibly more deep-seated origin and between soils and vegetation cover. In summary, it requires well-founded interpretation models besides an appropriate level of knowledge in geological mapping, computer processing and other techniques of data processing and presentation as well as the availability of independent data sources, e.g., ground control points.

14. There exists no unique complex interpretation model with which to extract from remote-sensing imagery the diverse information of interest to geologists. Analysis of soil type is very different from structural analysis. Thus image interpretation always requires image "filtering" by enhancing and/or undertaking a selective evaluation of image features based on spectral signatures relevant for the given survey tasks. So that it is first necessary to define the task properly and subsequently choose the most appropriate procedures and methods of data collection (including ground control), processing, evaluation and presentation.

15. The geological interpretation of remote-sensing data attempts to relate characteristics of the Earth's surface to sub-surface phenomena and causes. The crustal depth to which the surface interpretation might be extended downwards depends on the scale of features considered and on the method used.

16. Despite the mostly large scale of satellite remote-sensing imagery, its geological interpretation should not be restricted to a general survey but should strive to be as detailed as possible. This may be achieved by incorporating independent small-scale (large-resolution) information into the interpretation process, such as aerial photography or side-looking airborne radar (SLAR) images, available maps and ground verification. The results of thematic information extraction should be presented in as many different topical maps as possible (drainage, land forms, land use, soil types, vegetation, rock units, lithology, photolineations). Finally, the geologist

should try to determine the processes which could best explain the development of these various features and their interrelationships.

17. The endogenous forces that shape the Earth still persist; otherwise, the continents would be eroded to sea level within a time span of less than 15 million years. These processes lead, among others, to folding and faulting, to interaction with external forces of weathering and gravity and subsequently to erosion and redeposition. Planar and linear features related to these processes may be recognized on satellite images even if their intensity is very low. While ongoing internal geological processes normally result in broken symmetry and in homogeneity of features, erosion and redeposition tend to homogenize.

18. Many of the relief-forming processes of the continents are connected with lineaments. The latter are frequently related to scarps or other slope effects. These morphological features as well as differences in igneous or sedimentary rock types are recognized in remote-sensing imagery only indirectly owing to differential erosion, differences in soil porosity and water saturation, differences in tone or colour or those resulting from shadowing effects (especially in SLAR imagery). Reliable and quantifiable information about material composition can be derived only under favourable circumstances, which include the availability of high-resolution spectral data collection, appropriate processing and calibration by means of ground control data.

19. In most cases, it is not possible to identify the true nature of each individual feature seen or "suspected" by an interpreter in remote-sensing images or to find its location on the ground, especially since any visual interpretation process is not free of the influences of subjectivity, background knowledge and model concepts. Therefore, generalization and sometimes statistical evaluation of feature patterns derived from remote-sensing imagery are indispensable. Geological interpretation can go beyond the pure documentation of such features and should attempt to provide an understanding of the process. In this context, it should be noted that various rock types will react very differently when being subjected to the same type of crustal deformation. Granites, for example, will react with brittle fracturing while limestone would yield with folding.

20. Geological features that are recognizable in remote sensing not only permit inferences with regard to current status and past processes, but also allow the interpreter to draw, with different degrees of reliability, some conclusions with regard to future geologic events such as landslides or earthquakes.

B. Fundamentals of remote sensing

21. In its most general sense, remote sensing is the observation of a target (object) by means of a device (sensor) which is separated from the target by a given distance. Specifically, remote sensing of the Earth by satellites is the observation and measurement of the energy and polarization characteristics

of the emitted and reflected radiation of elements of the land, ocean areas and atmosphere of the Earth in different ranges of the electromagnetic spectrum. Information obtained through such a process can be used to describe the location, nature and time variation of natural parameters, phenomena and resources of the Earth's environment as well as of man-made objects and formations.

22. However, in order meaningfully to apply remote-sensing techniques, it is necessary for the user to be thoroughly familiar with the basic physical laws which govern the interaction of electromagnetic radiation with matter. These interactions, often referred to as the spectral properties of matter, are its reflectance, absorptance and transmittance.

23. In many remote-sensing applications, the use of various types of sensors, platforms and kinds of data collected at various altitudes (including also ground sampling) becomes essential since no single remote-sensing device or type of platform can provide the great variety of data required for complex and reliable interpretation.

24. Availability, continuity and timeliness of remote-sensing data as well as assured access to the data at a reasonable cost are among the factors that determine the benefits to be derived from remote sensing and its widespread incorporation into Earth information systems and decision-making processes. To date, such user-friendly and low-cost operational satellite systems which could provide such services or stimulate a sustained development in this direction are not yet in place.

C. Analog and digital image processing and photo-interpretation

25. The availability of multispectral aerial and satellite imagery has led to the development of new techniques for both image processing and photo-interpretation. While the human eye can differentiate only some 15 to 25 grey levels, it may distinguish thousands of shades of colours and hues. Multichannel projectors (with additive colour viewers) such as the MSP-4 multispectral projector allow the superposition of information contained in multispectral imagery in a way suitable for visual (analog) image interpretation. Such instruments also permit analog image processing and contrast enhancement such as the addition, subtraction and ratio of different spectral bands of the same image, which otherwise would require arithmetic operations by means of computers using digital remote-sensing data. However, digital image processing is more versatile, quantifiable and objective.

26. Image enhancement is the deliberate modification of an image in order to highlight selected spectral, radiometric and/or spatial features or areas on it. Multispectral classification is an information extraction process that analyses the spectral properties of data and then assigns each pixel to different classes on the basis of similar spectral signatures. This classification may be either supervised or unsupervised depending on whether the assignment to a class is based on spectral signatures determined for real

reference (calibrated) objects within the scene or whether it differentiates the scene only on the basis of predetermined spectral parameters (i.e., in the spectral domain only). More advanced classification techniques include those known as cluster analysis of the minimum-distance type, the maximum likelihood techniques and classification techniques using potential functions.

27. The availability of digital multispectral data from the LANDSAT programme accelerated the development and use of digital image processing in the mid-1970s. Computer-aided automatic or interactive image processing and analysis is becoming universal although its data products are still predominantly aimed at image enhancement and rectification, i.e., at providing optimal data presentations for visual interpretation. In addition, statistical analysis and classification of features as well as corrections made on the basis of multi-source data are more common. Image restoration processes recognize and compensate for data errors, noise and geometric distortion introduced by atmospheric effects, the scanning process, data transmission and reception.

28. Digital image processing of photographs requires the conversion of different image tones into different electrical signals that are subsequently digitalized. A broad variety of devices such as flat-bed scanners, drum scanners, laser-beam and television-scanning devices of different spatial and densitometric resolution is available today. Participants were introduced to instruments, both analog and digital, which could be used for image processing, viewing, map and image analysis.

29. Photo-interpretation of remote-sensing images is still the predominant use for such data in geology. In this very interactive interpretation process, the data are combined with information from other sources such as topographic and geologic maps, statistics and field data. An experienced photo-interpreter will identify features in the images chiefly by looking for differences or similarities in shape, size, pattern, structure, texture, topographic location, colour and tone. Their interpretation requires thorough knowledge of feature-context-cause relationships and of respective interpretation models.

D. Spectral response of surface objects in the visible, infrared and microwave range

30. In the visible, near and thermal infrared ranges of the electromagnetic spectrum, there are several pronounced absorption bands for iron as well as for various minerals (especially clay minerals) and rocks. High spectral resolution data in these spectral bands are therefore of promise in differentiating between various types of soils as well as between unaltered and altered (hydrothermally mineralized or weathered) rocks. However, the spectral resolutions required (about 1.5 nm) for detailed geochemical analysis or for mineral and rock discrimination (better than 40-100 nm) are not yet available on an operational and imaging basis.

31. Electromagnetic radiation observed in the visible and near infrared bands consists of reflected or back-scattered solar radiation, while thermal infrared energy, which is generally recorded in the two main atmospheric "windows" centred around 7 µm and 5 µm as well as in the 8-12.5 µm region, is emitted by the elements of the Earth's surface. The radiant emittance of an object depends upon its temperature and emissive properties. The emissivity of an object is the ratio between its real radiant emittance and that of a black body of the same temperature. The emissivity of magmatic rocks shows a minimum in the wavelength range between 8.5 µm and 11 µm with a shift to longer wavelength as the mineral content of the rocks becomes higher. Nevertheless, this potential for discrimination cannot yet be exploited to the limited spectral radiometric resolution of thermal infrared sensors owing to the fact that the emitted energy in this spectral range varies strongly with temperature.

32. Surface temperature is a carrier of geological information. However, it is influenced by many factors related to the sun, wind speed, air temperature, surface roughness, surface colour, humidity and plant cover. Geological information from the deeper crust is brought to the surface by geothermal heat flux. While daytime temperature measurements of the Earth's surface are rather noisy, with only a relatively small signal of geological relevance, repetitive observations during the night yield information about differences in thermal inertia of the material of the upper soil/rock layer. The thermal inertia of an object depends upon its moisture content, porosity and density. Analysis based on this property has been used successfully only on an experimental basis. Thus, the analysis of thermal infrared images is often combined with the use of images in the visible range.

33. The application of thermal infrared sensing in geology is especially promising in the following areas: (a) localization and monitoring of thermal anomalies connected with volcanic and geothermal activity and exploration of geothermal energy; (b) localization of temperature anomalies in connection with uranium and sulphuric ore exploration; (c) lithological mapping; (d) regional structural mapping; and (e) geological and geophysical engineering investigations.

34. While clouds and fog are practically opaque to electromagnetic waves in the visible and infrared range, they are transparent to microwaves in the centimetre and decimetre ranges. The microwave emissivity, reflectivity and penetration depth (skin-depth) properties of an object are mainly determined by its complex dielectric constant and thus by its electric conductivity. Since small amounts of water in soils and rocks change their electric conductivity drastically, the quantitative estimate of moisture content in soils and vegetation cover is one of the most attractive applications of passive microwave remote sensing. The apparent radiometric temperature and the reflectivity of objects observed in the microwave range depend, additionally, on the type(s) of material within the skin-depth and on the wavelength, polarization and angle of observation of the microwave radiation. To date no theory which takes all these parameters into consideration has been developed. Comprehensive collection of ground control is thus indispensable

for the proper interpretation of both passive and active microwave (imaging radar) data.

35. The strong influence of the texture of objects on the back-scattered radar energy can be of great help in identifying soil and rock types and vegetation cover, but this effect can be fully exploited only when measurements at different frequencies are available. This is not yet the case in most operational systems. A field experiment carried out by the Jet Propulsion Laboratory (United States of America), in Death Valley, where a great diversity of scales in surface roughness exists (salt deposits, sand, gravel, dunes, badlands, erosion features), has clearly demonstrated the potential of radar for separating various classes of objects according to their differences in surface roughness. A comparison between theoretical predictions and observed differences in radar brightness for these various classes showed good agreement in more than 70 per cent of the cases. Thus, surface elements which were not discernible on the basis of their colour and brightness in visible and near infrared images could be clearly differentiated on the basis of radar data.

36. One main advantage of radar imagery for applications in geology is its low viewing angle (especially in the case of SLAR). Even subtle geomorphologic-structural features are strongly emphasized as a result of radar shadows. Another benefit is the elimination of the screening effect of vegetation, which in conventional black-and-white photography masks details in rocks at the surface and in the topography. Radar imagery also enhances the photographic contrast between unconsolidated geologic units and bedrock. Alluvium, lacustrine deposits, landslide debris and similar units appear dark in tone and contrast sharply with more consolidated units. Different kinds of bedrock units, however, are indistinguishable on the radar imagery except where such units engender a characteristic form of topographic expression.

37. Radar imagery is particularly suitable for the detection of faults and other linear geomorphological features. They are most clearly visible when being illuminated by the radar beam perpendicular to their strike. Although radar shadowing causes some loss of information, about 70 per cent of linear features may be discernible in a one-side-look image, as compared to about 90 per cent in the case of a dual-look image. A combination of radar and multispectral satellite imagery has the additional advantage of compensating for the loss of information in the radar shadows and of combining the benefits of multispectral and detailed relief information.

E. Interpretation of satellite images for geological purposes

38. One of the key elements in geological interpretation of remote-sensing imagery is the identification, characterization and classification of photo-lineations. They may be related to ground features of different origin and surface expression such as linear depressions, fractures or joint zones, boundaries of soil types, lithological borders and bedding trends. Classifications of photo-lineations should take into account the area under

investigation, their length, direction, frequency and density, their morphology (negative, positive, drainage-related), structural type (simple, complex) and their detailed internal structure and contrasts in tone.

39. Lineaments are more frequent in areas of outcropping basement rocks than in those with platform covers. Drainage patterns indicate fault systems, watershed positions, morphology and differences in rock type and permeability. Although the main genetic types of faults (dip-slip, transcurrent and upthrust faults) tend to show some systematic differences in general surface appearance, their discrimination in satellite imagery is not yet satisfactory. Only 5-10 per cent of the lineaments identified in such imagery can be generically classified, with the proper identification of thrust faults being the most difficult. One obtains a higher percentage of accurate identification of fault types when working with aircraft images.

40. The interpretation of satellite images for geological problems may be approached in a variety of ways. One of these is to obtain more complete information about an object of interest by a combined analysis of many different types of images and independent contextual information. Another possibility is to learn more about the connection between superficial image features and deep-seated structures and causes. Neo-tectonic block movements often result in a higher frequency of photo-lineations. The distance relationships between them yield information on their depth extension, vertical "amplitude" and horizontal scale. They are positively correlated, thus allowing image interpretation at various levels. A third approach is to decipher the historical development of a section of the Earth from recent manifestations of patterns of image features and their mutual relationships. The offsetting or cross-cutting of older fractures, dykes, folds or rock units by younger ones is a typical example which allows the inference of relative age differences. Finally, information about geochemistry and/or mineralogy can be extracted within the limitations discussed in paragraphs 30 and 31 above.

F. Role of remote sensing in assessing geological hazards

41. One of the main applications of geological interpretation of remote-sensing imagery and other data derived from space techniques (e.g., on recent crustal movements) is to study recent and ongoing geological processes in order to assess geological hazards. The latter are diverse (such as earthquakes, landslides and volcanic eruptions) and are often intricately interrelated.

42. The first step in evaluating a geological hazard is to study the Neogene-Quaternary evolution of the territory of interest. Recent geological structures such as scarps, narrow depressions, linear zones of abundant watering or peculiar vegetation often appear more pronounced than ancient geological structures in satellite images. Areas of concentrated occurrence of recent crustal deformations are considered to be of potential seismic risk although not all recent structures, and faults in particular, have retained

their high activity. Thus it is important to determine the trend of neo-tectonic evolution of the region under study by determining whether movements in any specific place have accelerated or slowed down, and whether any restructuring has occurred. Space photography from the south-western Syrian Arab Republic revealed two major neo-tectonic elements of a northern and north-eastern trend. According to geological data of the Pliocene-Quarternary age, the former direction cuts across the latter and older direction (active until the Miocene period) in a right-lateral sense. Consequently the north-trend structures pose a greater seismic hazard.

43. In order to distinguish and map active faults, aerial and space images of different scales and types have to be evaluated. Images taken in the near infrared are especially useful for the analysis of fine relief features and are also very sensitive to variations in vegetation, which is sometimes even more indicative of Holocene activity of faults than changes in topography. SLAR images emphasize topography and help to make visible even subtle differences in elevation. In other areas, thermal infrared airborne images may be particularly useful in detecting soil moisture related to active fault zones. Lateral strike slipping of faults may be indicated by consistent curving or river valleys and gullies or by horizontal offsetting of alluvial fans with respect to their feeding valleys. Normal dip-slip or thrusting of faults are indicated, instead, by geomorphological scarps, variations in the depth of the fault-line cut in the terrain, the splitting of terraces and variations in their height. The recognition of these features requires high-resolution stereoscopic images.

44. Information derived through remote sensing can play only a complementary role in the required complex assessment of geological hazards. This information has to be evaluated together with the results of independent geological, geophysical, geochemical, geodetic and landscape observations, and repeated surveys are indispensable. This also applies to the monitoring of slow changes, such as creeping disasters, which are connected with the advance of erosion or sedimentation, desertification, salinization or to developing swamps due to alterations in the coastlines of seas and lakes and other geologically induced changes in the landscape.

G. Application of remote sensing for prospection of mineral deposits

45. The potential contributions of remote sensing to the exploration of both vein mineralization and strata-bound potash and salt deposits in the eastern parts of Germany were demonstrated by means of case studies conducted in the Harz Mountains and in the Vogtland. Emphasis was placed on identifying surface expressions of hydrothermal veins under conditions of humid climate and intense cultivation, i.e., of an anthropogenically heavily overprinted Earth's surface.

46. Vein mineralizations are bound to late Mesozoic uplifted blocks and genetically related to late Hercynian magmatism. In some cases they are also related to Permian volcanic activities as well as to a regional mobilization and circulation process generated by vertical block movements but without a clearly defined relation to magmatic activities. In case of the Vogtland mineralizations and their relationship to the regional water circulation regime (manifested in numerous mineral springs), a possible connection with local swarm earthquake activity was discussed in terms of natural liquid-induced seismicity.

47. Remote-sensing interpretations related to the exploration of mineral deposits in the eastern parts of Germany were based on Soviet Kate-200 and LANDSAT images, complemented by data from aerial photography (both high-flying aircraft and low-flying helicopter) and SLAR missions as well as ground-based field spectrometer measurements. These data, together with additional independent geoscientific results, were used to complement available knowledge about local and regional fault patterns and their mutual relationships, thereby yielding fresh insights into already known mineralizations, their genesis and their wider potential. The remote-sensing interpretations and inferences made by the participants were checked during field exercises in the training areas.

48. The major conclusions derived by the participants from these exercises were as follows: (a) the circulation of hydrothermal solutions is mainly controlled by the less mineralized principal faults; (b) the vein structures in the inner parts of block segments owe their mineralization to water circulation; (c) the photo-lineations identified in the remote-sensing data were dominated by morphological structures (mostly negative forms), water circulation (lower spectral reflectance), zones of hydrothermal alteration (higher spectral reflectance) and offsets of morphological magmatic veins and quartz zones sticking parallel to the fluorine spar vein structures; (d) the relative temporal succession of the tectonic elements could be determined by the criteria of cross-cutting faults; (e) the best results were achieved where remote-sensing data could be complemented by independent, detailed data from geophysical and pedo-geochemical mapping and by other geoscientific primary data; and (f) the combined analysis of various data sources maximizes information output, minimizes prospecting costs and leads to optimal selection of areas for detailed studies.

H. Remote-sensing applications in hydrogeology and water resources surveys

49. The use of remote sensing in hydrogeology is complicated by the fact that groundwater is not visible in the images. Thus, indirect inferences have to be drawn from surface features. Hydrogeological applications are further impeded by humid climate, dense vegetation cover and anthropogenic features.

50. During the past few decades, new remote-sensing techniques such as multispectral imaging in the visible spectrum, in the near and far infrared range as well as in the microwave range (radar) have made it possible to solve successfully many hydrogeological problems. Satellite airborne imagery is interpreted to show the prevailing rock types and potential aquifers. Drainage patterns provide information on the permeability of aquifers; repeated observation is indispensable in regions where drainage patterns change seasonally. In hydrogeological applications, geo-botanical information can be very useful. Particularly in semi-arid regions, the density of vegetation cover often reflects the amount of moisture in the weathered zone as well as the quality of water; it also provides insights into the tectonic features. As compared to conventional ground-based hydrogeological mapping, the survey time and cost for comparable map scales can be reduced by about 20-50 per cent by incorporating remote-sensing data.

51. In densely vegetated areas, relative changes in the groundwater level may be estimated from the leaf reflectivity and height of the canopy of the plant species considered. Groundwater pollution (e.g., by oil substances, heavy metals, cyanides and nitrogen compounds) affects leaf and canopy reflectance, particularly in the near infrared spectral range; thus, the degree and spread of water pollution may be detected and monitored.

52. Through remote sensing in different spectral ranges it is possible to determine with varying degrees of accuracy, in less time and at a smaller cost, several parameters of the water budget, such as infiltration, run-off, evapo-transpiration, soil humidity (although only in the uppermost tens of centimetres of the soil profile) as well as the location and quantity of inflow of groundwater to surface flow. Because of the unique spectral signature of water, remote-sensing imagery in the visible or near infrared is also particularly well suited for mapping and inventory of surface water bodies (lakes, ponds and fluvial environments). Repetitive observation of watershed areas can also play an important role in predicting water run-off during flood regimes and annual water availability, and thus contribute to improved planning of water exploitation, river navigation, management of water storage and discharge of dams for hydroelectric power and irrigation schemes. Remote sensing is also a powerful tool for monitoring water temperature and quality (e.g., water transparency, amount of suspended material, chlorophyll) or pollutants. All these factors were extensively discussed on the basis of a case study in West Africa.

I. Application of remote sensing to the study of arid and semi-arid lands

53. As a result of inaccessibility or climatic conditions adverse to man, it is often difficult to obtain needed geological and other environmental or cartographic data from arid or semi-arid lands by conventional methods. Therefore, repetitive and synoptic remote-sensing data, mainly from satellites, are of greatest value for quick investigation of these regions, for preparing resource inventories, monitoring environmental changes such as

progressive desertification and salinization of soils, assessing the grazing capacity of sparsely vegetated pasture areas as well as for geologic-tectonic, geomorphological and soil mapping.

J. Application of mathematical methods in remote sensing

54. Presentations were dedicated to the evaluation of multivariate data. Starting from general considerations with regard to the existence, generation and use of multidimensional features in geosciences, algorithms for decision-making were presented and demonstrated through simple examples.

55. The concept of unsupervised versus supervised classification was presented and demonstrated for the case of digital image processing. Particular attention was paid to the practical application of these algorithms under real conditions. With this aim, a presentation was given on two procedures used at the Central Institute for Physics of the Earth Potsdam. These procedures allow the interactive optimization of classifiers, the computer-aided quality control of the classification results and the possibility to combine different algorithms.

56. Fractals may be more than a mathematical curiosity. They offer a compact method for describing objects and formations. Thus, they are first and foremost a language of n-dimensional geometry. Many structures in nature have an underlying geometric regularity, known as scale invariance or self-similarity. The repetitive pattern defines the fractal dimension of the structure. Remotely sensed pictures of the Earth's surface can be created, in principle, by random fractals using the midpoint-displacement method.

57. The technical interest of fractals comes from their suspected practical importance. As an example, petroleum-bearing rock which typically contains fluid-filled pores of many sizes might be effectively understood as a fractal object.

58. A great practical potential of fractal geometry is to use it to describe objects by means of certain fractal dialects which can significantly reduce the amount of data necessary to transmit or store an image. The time and cost of transmitting satellite images to the receiver stations on Earth can be reduced by transforming the images into codes using fractal algorithms. The application of fractal type mathematical methods in the analysis of remotely sensed images is a focus of intense study.

K. Remote sensing and comparative planetology

59. Space techniques provide a powerful way of studying the Earth as a planet. Although in most cases space techniques only allow measurements of surface phenomena by remote sensing, they do provide quantitative boundary conditions essential to the definition of the models. These include the knowledge of many diverse components such as the Earth gravity field, the

Earth deformations and mapping of geological structure, the ocean global circulation and the ocean-atmosphere coupling, and the atmosphere energy budget and radiative transfer. A global understanding of the various physical components and their interrelationships is a prerequisite to the understanding of the evolution of the Earth as a planet of the solar system. Of course, the same is true for all other planets of the solar system.

60. The direct exploration of the solar system with the possibility of in situ measurements of the other planets and their atmospheres and magnetospheres is providing additional information which is extremely valuable for the understanding of the history and evolution of the planet Earth. Access to the environment of other planets, coupled with in-depth studies of Earth phenomena and with theoretical models, is crucial to the understanding of the detailed balances which maintain the climate system of the Earth.

61. The technique of remote sensing has been applied to planets of the solar system in recent years. Spacecraft data show that one hemisphere of Mars is dominated by a moon-like surface with many eroded craters. The other hemisphere contains many younger, less cratered volcanic plains, canyons apparently formed from geological faults and several enormous volcanic mountains larger than any others known in the solar system. Mars is the only planet besides Earth known to have had a long-term dynamic hydrological cycle. Despite its cold, dry climate and extensive areas of cratered terrain left over from ancient times, Mars shows abundant evidence of the action of water and ice earlier in geological history.

62. Seen through a telescope the planet Venus appears as a nearly featureless disk covered with clouds. Photographs made by space vehicles parachuted onto Venus showed a relatively clear scene with scattered angular rocks at one site and eroded-looking, soil-sprinkled rocks at the other. Radar measures from Earth and space revealed impact craters distorted by the thick atmosphere, volcanoes shaped like pancakes, intricate networks of fractures and a mysterious lava channel that snakes several thousand kilometres across the planet. There is the hypothesis that large parts of Venus' surface were reworked during a huge volcanic episode 500 million years ago, similar to outbursts seen on Mars and the moon.

L. Field exercises in training areas

63. The lectures and classroom exercises were complemented by field exercises in different training areas (Vogtland region and Sub-Hercynian basin/Harz border fault). Their main aim was to verify the inferences drawn from the interpretation of various types of remote-sensing imagery made during the course and from spectral signature measurements obtained under humid climate conditions.

64. In the Vogtland training area the following questions were discussed and related features demonstrated: (a) representation and characteristic features of the granite massif of Vergen as it affected land use patterns and

morphological features seen in remote-sensing imagery; (b) geology of the characteristics of rocks; (c) thematic interpretation of fold structures and of hilly terrain caused by diabasic monadnocks; and (d) interpretation of data based on remote sensing, geomorphology, geology and seismology in order to reveal relationships between tectonics, deformation features and local earthquakes.

65. The field exercise in the Sub-Hercynian basin and the Harz Mountains aimed mainly to illustrate: (a) the detection of different rock types and faults along the northern border fault zone of the Harz Mountains; (b) ground verification of the spectral characteristics of rock types by means of field spectrometer measurements; (c) field checking of fault zones characterized as linear zones of increased moisture content; (d) pattern recognition as a tool for rock discrimination; and (e) demonstration of the kinematic aspects of block tectonics under the uplifting conditions of the Harz block.

Annex I

PROGRAMME OF THE COURSE

Date	Time	Subject	Speaker
Tuesday 8 October	10-11 a.m.	Opening ceremony	
		Welcome address on behalf of the United Nations	H. J. Haubold (United Nations)
		Welcome address on behalf of the Carl Duisberg Society	B. Schleich (Germany)
		Welcome address on behalf of the Free University of Berlin	W. Schunack (Germany)
		Welcome address on behalf of the Central Institute for Physics of the Earth	E. Hurtig (Germany)
	11 a.m.-12.30 p.m.	Geology and remote sensing	P. Bankwitz (Germany)
	2-4 p.m.	Remote sensing and digital image processing: current status and trends	F. K. List (Germany)
Wednesday 9 October	9.30 a.m.- 12.30 p.m.	Introduction to the physics of remote sensing	F. K. List (Germany)
	2-4.30 p.m.	Data acquisition: remote sensing systems - photography, scanners, microwave systems	F. K. List (Germany)
Thursday 10 October	9.30 a.m.- 12.30 p.m.	Visual interpretation and digital image processing	F. K. List (Germany)
	2-4.30 p.m.	Hands-on demonstration: digital image processing (exercises)	F. K. List Ch. Bauer W. Koch Ch. Munier R. Schoele (Germany)

Date	Time	Subject	Speaker
Friday 11 October	9.30 a.m.- 12.30 p.m.	Digital image processing: application to geology with introduction to fieldwork (exercises)	P. Bankwitz H. U. Wetzel E. Bankwitz J. Pilarski J. Fritz (Germany)
	2-4.30 p.m.	Hands-on demonstrations: image processing and geological information systems (exercises)	F. K. List Ch. Bauer Ch. Munier W. Koch R. Schoele M. Schultz (Germany)
Saturday 12 October		Excursion to Potsdam	
Sunday 13 October	9 a.m.-3 p.m.	Excursion to the Christian Memorials of Martin Luther in Wittenberg	
	3-6 p.m.	Transfer to fieldwork (Vogtland block)	
Monday 14 October	9 a.m.-4 p.m.	Fieldwork in the Vogtland area: practical exercises, mapping based on geological fieldwork, aerial photo and satellite interpretation for mineral exploration and seismological events	P. Bankwitz J. Pilarski H. Kaempf (Germany)
	7.30-9 p.m.	Seismic hazards and remote sensing	V. Trifonov (USSR)
Tuesday 15 October	9 a.m.-3 p.m.	Continuation of fieldwork in the Vogtland area	
	3-6 p.m.	Transfer to the Harz Mountains	

Date	Time	Subject	Speaker
Wednesday 16 October	9 a.m.-4 p.m.	Fieldwork in the Harz Mountains and its foreland: interpretation of main fault structures, texture pattern of crystalline basement and sedimentary cover rocks, spectral characteristics of soil and rocks, exercises with mobile spectrometers	
		Geological exercises	P. Bankwitz E. Bankwitz J. Pilarski J. Fritz (Germany)
		Spectrometer exercises	H. Loeper W. Herr (Germany)
Thursday 17 October	9 a.m.-4 p.m.	Continuation of fieldwork in the Harz Mountains	
	4-6 p.m.	Transfer to Potsdam	
Friday 18 October	9 a.m.-12.30 p.m.	Remote sensing applications for hydrogeological projects in developing countries	W. Kruck (Germany)
	2-5 p.m.	Interpretation of remote-sensing data and development of geological models	P. Bankwitz
Saturday 19 October		Excursion to Berlin	
Sunday 20 October	9 a.m.-11.30 a.m.	Remote sensing - comparative planetology (Mars-Earth-Venus)	H.-P. Joens (Germany)
Monday 21 October	9 a.m.-12.30 p.m.	Remote-sensing applications in tropical Africa (geology, environment, soil, vegetation, forest)	M. Punkari (Finland)
	2-5 p.m.	Application of remote sensing to the study of arid and semi-arid lands	T. Woldai (Netherlands)

Date	Time	Subject	Speaker
Tuesday 22 October	9 a.m.-12.30 p.m.	Case study of remote sensing-aided geological mapping in Egypt	F. K. List (Germany)
	2.30-5 p.m.	Remote-sensing applications in water; case studies in West Africa	M. Antoninetti (Italy)
Wednesday 23 October	9-11.30 a.m.	Trends in recent digital cartography; creation of geoscientific maps	B. Meissner U. Ripke J. M. Grunicke (Germany)
	1.30-3.30 p.m.	Geostatistics and mathematical modelling for geological analysis	J. Harff B. Lewerenz (Germany)
	3.30-5 p.m.	Remote sensing and geomorphological analysis for neotectonic interpretation; problems of fractal geometry in remote-sensing data	J. Pilarski (Germany)
Thursday 24 October	9-10.30 a.m.	Trends of remote sensing in application of the ESA programme	J. Lichtenegger (Italy)
	11 a.m.-1 p.m.	Final discussion	
	2-4 p.m.	Closing ceremony	P. Bankwitz Ch. Kamlage E. Hurtig F. K. List (Germany) H. J. Haubold (United Nations)

Annex II

LIST OF PAPERS PREPARED FOR THE TRAINING COURSE

1. Antoninetti, M., Remote sensing applications in water - case studies in West Africa, Milan, Italy.

2. Bankwitz, P., Geology and remote sensing, Potsdam, Germany.

3. Bankwitz, P., Interpretation of remote-sensing data and development of geological models, Potsdam, Germany.

4. Bankwitz, P., Wetzel, H.-U., Bankwitz, E., Pilarski, J., and Fritz, J., Introduction to fieldwork in remote sensing (Vogtland, Harz Mountains), Potsdam, Germany.

5. Harff, J., and Lewerence, B., Geostatistics and mathematical modelling for geological analysis, Potsdam, Germany.

6. Joens, H.-P., Remote sensing - comparative planetology (Mars-Earth-Venus), Clausthal-Zellerfeld, Germany.

7. Lichtenegger, J., Trends of remote sensing in application of the ESA programme, Frascati, Italy.

8. List, F. K., Remote sensing and digital image processing: current status and trends, Berlin, Germany.

9. Punkari, M., Remote sensing application in tropical Africa, Helsinki.

10. Trifonov, V. G., Seismic hazards and remote sensing, Moscow.

11. Woldai, T., Application of remote sensing to the study of arid and semi-arid lands, Enschede, Netherlands.

12. The Participation of the United Nations System in International Space Year, United Nations, New York.

13. Project Document: Centre for Space Science and Technology Education, SAP/90/001/002/003/004, United Nations, New York.

UNITED NATIONS

A

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COMMITTEE ON THE PEACEFUL USES
OF OUTER SPACE

SIXTH UNITED NATIONS/WORLD METEOROLOGICAL ORGANIZATION/EUROPEAN SPACE AGENCY TRAINING COURSE ON THE USE OF VISIBLE, INFRARED AND MICROWAVE SENSOR SYSTEMS IN HYDROLOGICAL AND AGROMETEOROLOGICAL APPLICATIONS, ORGANIZED IN COOPERATION WITH THE GOVERNMENT OF PERU

(Lima, 7-25 October 1991)

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INTRODUCTION

A. Background and objective

1. At its thirty-seventh session, in its resolution 37/90 of 10 December 1982, the General Assembly endorsed the recommendations of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE 82) and decided, among other things, that the United Nations Programme on Space Applications should organize training courses on advanced space science applications and new developments for the benefit of Member States, particularly the developing countries.

2. The United Nations/World Meteorological Organization (WMO)/European Space Agency (ESA) Training Course on the Use of Visible, Infrared and Microwave Sensor Systems in Hydrological and Agrometeorological Applications was one of the activities of Programme on Space Applications for 1991 that were endorsed by the General Assembly in its resolution 45/72 of 11 December 1990. The training course was organized in cooperation with the Government of Peru and hosted by the Comisión Nacional de Investigación y Desarrollo Aeroespacial (CONIDA) at Lima from 7 to 25 October 1991 for the benefit of participants from the Economic Commission for Latin America and the Caribbean (ECLAC) region.

3. The objective of the course was to provide education and practical hands-on training to participants on various aspects of current and future visible, infrared and microwave remote-sensing systems, including the acquisition, processing, interpretation, applications and archiving of the data generated by such systems. Particular emphasis was to be placed on satellite radar systems and on the use of their data in hydrology, agrometeorology, forestry and oceanographic applications.

4. The present report, which covers the background, objective and organization of the course as well as a summary of the lectures presented, has been prepared for the Committee on the Peaceful Uses of Outer Space and its Scientific and Technical Subcommittee. The participants will report to the appropriate authorities in their respective countries.

B. Organization and programme

5. The participants were professionals with several years of experience in agronomy, meteorology, hydrology, forestry, agrometeorology and remote sensing. The co-sponsors jointly selected 24 participants and 5 observers from the following 14 countries: Argentina, Bolivia, Chile, Colombia, Cuba, Ecuador, Guatemala, Honduras, Mexico, Netherlands Antilles, Panama, Peru, Uruguay and Venezuela. Instruction was provided by experts from Canada, Peru, WMO, ESA and the United Nations (Outer Space Affairs Division).

6. Funds allocated by the United Nations, WMO and ESA for the organization of the training course were used to defray the cost of international air travel and daily subsistence allowance for 18 participants from the ECLAC region. The Government of Peru, through CONIDA, provided the course's classroom and laboratory facilities, consumable materials and local transportation for all participants.

7. Opening addresses were presented by Mr. Ricardo Coloma, Institutional Head, CONIDA, on behalf of the Government of Peru, by Mr. Jean-Pierre Guignard on behalf of ESA and by Mr. Sergio Camacho on behalf of the United Nations. A statement from Prof. G. O. P. Obasi, Secretary-General of WMO, was also read at the opening ceremony.

I. OVERVIEW OF THE COURSE

A. Introduction and scope of the course

8. There have been accelerated improvements in remote-sensing systems and in the computer hardware and software used to analyse and extract information from the data that is being acquired by these systems. As the new generation of Earth-observing satellites, particularly the radar satellites, are launched and become operational, an increasing amount and diverse type of data is becoming available. Radar satellites will provide data over frequently cloudy areas that could not be monitored in the past. The use of these microwave data along with data obtained in the visible and infrared portions of the electromagnetic (EM) spectrum in Geographic Information Systems (GIS) will become a powerful tool to monitor, manage and protect the natural resources and the environment of the Earth.

9. For a profitable use of such technological resources, it will be necessary to form groups of specialists who understand and can apply these rapidly evolving technologies. The course was designed to provide participants with the knowledge of the physical principles involved in remote sensing in various regions of the EM spectrum, the issues associated with the acquisition and processing of the data and the use of multi-temporal, multi-sensor data in specific applications.

10. Radars used for remote-sensing purposes may be grouped into three different categories: altimeters, scatterometers and imaging radars. Specialized applications use altimeters to determine the altitude of an object, e.g., a satellite, above ground level; their applications are usually to determine land and ocean topography. Scatterometers are used to determine wind speed over a sea surface or as data to assist in the analysis of other radar data. Imaging radar can provide picture-like representations of the observed scene and finds its applications primarily in natural resource surveys and environmental monitoring. The microwave portion of the course focused primarily on imaging radars and on the analysis and interpretation of their data.

B. Fundamentals of remote sensing

11. The development of remote-sensing applications requires a knowledge of the scientific principles underlying remote sensing, including the propagation of electromagnetic radiation through the atmosphere, the interaction of radiation with matter, the detection of radiation by the sensor systems and the generation of images in photographic or computerized form. The sensors themselves are classified as imaging or non-imaging depending on whether the sensor data can be converted into a map-like representation of the scene observed. Remote sensing deals primarily with imaging sensors. Sensor systems are also classified as active or passive systems depending on whether they supply their own source of radiation, as in the case of radar, or use natural radiation, as in the case of photographic systems.

12. Airborne photographic cameras are still commonly used remote-sensing systems. The advantages offered by aerial photography include geometric accuracy, stereoscopic relief information, a broad range of image scale and coverage depending on the flight altitude and camera focal length, a broad choice of film-filter combinations to select spectral bands, well-established procedures for acquiring and interpreting images, a large number of experienced photo-interpreters and photogrammetrists and the flexibility of acquiring images at the desired time and place.

13. Photographic systems are sensitive to the visible portion of the electromagnetic spectrum and to portions of the ultraviolet and near infrared regions. Because shorter wavelength radiation is scattered more by the atmosphere, resulting in hazy images, the ultraviolet band is not commonly used for remote-sensing purposes, and blue light is often excluded in favour of near infrared radiation. Thus, the three commonly used bands in colour photography in remote sensing are the green, red and infrared bands. The selection of photographic spectral bands, through the selection of films and filters, is determined by the spectral characteristics of the objects to be studied. Colour infrared film (with filters to eliminate blue light), for example, is used to study vegetation since green leaves are highly reflective in the near infrared and that reflectance is sensitive to vegetation type and condition.

14. The information obtained from aerial or space photography is generally used to create a map or is transferred onto a map. This can be done either by tracing features from the photograph onto a transparent overlay, by visually comparing features of the photograph with corresponding features on a map and transferring information freehand or by using equipment that optically or digitally superimposes the photographic image on the map.

15. Photo-interpretation involves the identification and evaluation of features on a photograph that are considered significant for some applications. The photographic elements on which the identification and evaluation are based are the size, shape, tone and colour, texture, pattern, shadow, site and association of the various features on the photograph.

16. Visual interpretation of satellite imagery is an extension of photo-interpretation of aerial photography, differing mainly in that the large scale of the satellite imagery and the lack of stereoscopy (except in the case of some SPOT data) make features less easily recognizable. While an untrained viewer can recognize many common features such as trees, rows of crops, buildings, roads and animals, on a small-scale aerial photograph these features are generally too small to be seen on satellite imagery, and few untrained viewers can reliably interpret the larger features. Information must often be deduced from seemingly abstract textures, patterns and associations. Satellite image interpretation, therefore, tends to be more theoretical and more specialized than photo-interpretation. The repetitive nature of satellite data is often useful in interpretation since images from different seasons or years will show changes that indicate the nature of the area.

17. The information gathered by a sensor system in each of possibly many spectral bands can be converted digitally into an image form. The image can then be represented in black and white with varying grey tones or in colour with varying colour hues. For each band the intensity of tone or hue is proportional to the amount of radiation that was reflected, emitted or back-scattered by an object (target) on the surface being observed. When the primary colours (blue, green or red) are assigned arbitrarily to each spectral band and two or three of the bands are superimposed, the resulting composite image will contain a wide range of colours where each colour is the visual effect of superimposing the primary colour hues corresponding to an object on the ground. Knowing the spectral properties of various targets (e.g. water, vegetation, soil) in the spectral bands in which the sensor system gathered the information, the primary colour that was assigned to each band and the theory of colour, the user would be able, qualitatively, to make a first level identification of most of the objects that appear in the image. For many applications this accuracy and level of classification is sufficient.

18. Since the tones of grey or the digital values that represent an image are a measure of the radiation received by the sensor, a user can perform either a qualitative or a quantitative radiometric analysis or perhaps both. For accurate image analysis and interpretation it is essential that the user have a thorough understanding of the physical processes involved in the creation of an image. This implies being familiar with the two basic principles of radiometry, which are: (a) the validity of the principle of superposition for wavelike phenomena; and (b) the linearity of sensor response to radiation coming in its band of operation.

19. One of the limiting factors in using remote sensing on an operational basis has been the lack of data in time periods that are most adequate for optimal discrimination of features particular to a specific application. Because of cloudy conditions, a multi-temporal approach to land use also suffers from limitations of data availability. To some extent the off-nadir viewing capability of SPOT and the combined use of its data with Landsat's Thematic Mapper data have alleviated these limitations. However, in tropical areas which have excessive cloud cover, the capability of microwave radiation

to penetrate clouds and light rain showers could make radar imagery of particular value to developing countries.

20. Microwave remote sensing provides the capability for day or night observations and under clear sky or cloudy conditions. This is possible because most microwave sensor systems provide their own source of radiation (i.e., independent of the sun) and because microwave radiation, which is in the 0.3 GHz to 300 GHz (in terms of wavelength, in 1m to 1mm) portion of the EM spectrum, can penetrate through clouds and light rainfall.

21. Although radar systems are usually defined by the frequency interval in which they operate, they are sometimes designated by their wavelength of operation. This is done because newcomers to radar technology are usually more familiar with the concept of wavelength of the EM radiation. However, frequency is the more fundamental property of EM radiation since its frequency remains constant when it passes through media of different densities while its wavelength and velocity change. To transmit information, a carrier wave of a particular frequency can be modulated by varying the amplitude of the wave (AM modulation). An alternative way is to modulate the frequency (FM modulation); this method is less subject to interference and is the one commonly used to transmit high-quality signals.

22. Microwave sensors can be classified into passive and active systems. Passive systems measure microwave radiation emitted by the ground features or by the sun and reflected by the surface. Active systems "illuminate" the area under observation and measure the strength, phase and time delay of the radiation reflected by the ground features.

23. The interaction of microwave radiation with objects on the surface of the Earth depends strongly upon the electrical properties of the objects and the surface roughness relative to the wavelength of the incident radiation. The electrical properties of matter are determined by its dielectric coefficient, which is highly sensitive to water content. An analysis of the returned signal can therefore provide information on the nature of the objects, their relative size, distribution and moisture content.

24. Radar images can be obtained from either an aircraft or a satellite. In both cases, the images are obtained by transmitting microwave pulses at an angle to the vertical and measuring the intensity and time delay of each return pulse. The first return pulse corresponds to the object whose projected distance in the direction of the sensor system is the smallest. In general this pulse corresponds to the object closest to the flight path. Because of the geometry between the incident pulse and the height of objects, the projected distance in the direction of the sensor system of the upper part of an object is smaller than the distance of its corresponding ground-point projection. This effect is known as foreshortening and makes terrain of high relief appear in the image as falling towards the radar. On the images, foreshortening causes the slopes to become extended and to appear darker. This effect can be corrected with reference to a digital terrain map.

25. The foreshortening effect can become very severe so that the top of a mountain appears to be closer to the flight path than the foot of the mountain. This effect is called layover and cannot be corrected. Other image degradations include a speckle effect, which appears as noise on the image and is related to the frequency coherence of the system, as well as several effects due to the motion of an object with respect either to the sensor system or to other objects in the field of view of the radar.

26. Because the difference in distance between objects directly beneath an aircraft or a satellite is very small, the corresponding return signals often cannot be electronically discriminated. For this reason airborne radars have been designed to scan objects at some distance to one of the sides of the aircraft and are called side-looking airborne radars (SLAR).

27. The spatial resolution attainable from a radar system is independent of the altitude of the sensor platform and increases with the length of the antenna that transmits and receives the microwave pulses. A technique known as Synthetic Aperture Radar (SAR) which applies a linear frequency modulation to a transmitted long pulse in order to simulate a train of short pulses has been developed in order to keep satellite antennas reasonably small. The technique uses the Doppler shift of the reflected pulse due to the motion of the platform and a modified data processing to simulate a much longer antenna. The result is a higher resolution which is only limited by the power that the antenna is capable of transmitting.

28. The microwave spectrum is subdivided into various bands, each of which is referred to by a single letter and is determined by a specific range of frequencies, as follows:

Band name	Band limits (GHz)	Band name	Band limits (GHz)
P-band	0.225-0.390	K-band	10.90-36.00
L-band	0.390-1.550	Q-band	36.00-46.00
S-band	1.550-4.200	V-band	46.00-56.00
C-band	4.200-5.750	W-band	56.00-100.0
X-band	5.750-10.90		

For airborne radar missions, which account for the bulk of the microwave data gathered worldwide to date, the most used bands have been the X-band, L-band and the K-band. For the satellite radar systems of the 1990s, the predominant frequency will be the C-band.

C. Radar concepts

29. For most imaging radar systems, the geometric configuration is such that a microwave beam is radiated from the side of the platform, at an angle to the surface and perpendicular to the flight direction. The radar beam is wide in the vertical dimension and narrow in the horizontal dimension. A two-dimensional imaging plane is produced by the motion of the radar platform which periodically transmits pulses. Thus, continuous strips of the Earth's surface may be "viewed" parallel and oblique to the flight direction. The scanning concept of the imaging radar is, therefore, quite different from that used by scanners that operate in the visible and infrared regions of the EM spectrum. The latter build an image on a line-by-line basis, their viewing geometry is downward looking and the spatial resolution of the images depends on the angular resolution of the sensor system and platform altitude and degrades away from the nadir track.

30. Imaging radars do not depend on angular resolution; instead, their across-track resolution range is determined by measuring the time delays between the reflected signals due to the transmitted pulses. The range resolution depends upon the length of the radiated pulse which determines the distance by which two objects must be separated in order to be discriminated. This resolution increases as the radiated pulses become shorter. The azimuth along-track resolution is determined by the width of the microwave beam which is in turn determined by the length of the antenna. The azimuth resolution increases with the length of the antenna.

31. For SAR instruments, the limiting factor for their range resolution is shortening the transmitted pulse while maintaining sufficient power to detect the reflected signal. This is accomplished by coding the transmitted pulse through a linear frequency modulation, the so-called "chirped pulse". The range components of the return signal must be processed to obtain the corresponding resolution. Azimuth-related components of the same signal must similarly be processed to obtain the along-track resolution. Thus, the acquisition of SAR imagery requires a processing system that can operate on a two-dimensional array of signal data.

Instrumentation

32. A basic imaging radar system consists of a transmitter, a receiver, an antenna designed to transmit and receive microwave energy and a data-processing and recording unit. The transmitter generates a short microwave pulse with a duration of microseconds. This signal is transmitted by the antenna. The antenna directs a narrow beam into the range direction and receives the returned energy portion of this pulse. The design and form of the antenna determine the beam width and swath width of the "illuminated" ground surface.

33. The receiver measures the strength of the returned portion of the transmitted signal and relates the receiving time to the transmitting time in order to determine the range distance of the reflecting object relative to the

radar. The receiver converts the signal waveform from a frequency band suitable for radiation to an equivalent one that is suitable for recording. This requires a correlation process between the transmitter and the receiver. The recorder and processor units turn the raw data either into an optical record (e.g., on film) or into a digital record using high density digital tapes (HDDTs). Further processing of the radar return signals is necessary by means of correlating signal film or HDDT data to produce radar imagery or computer-compatible tapes respectively. The latter may then be used for digital display, image manipulation and analysis.

Microwave polarization

34. An electromagnetic wave consists of coupled electric and magnetic fields which oscillate at right angles to each other in a regular wavelike manner. The polarization of a waveform describes the orientation of the electric field sector at a given point in space during one period of oscillation. In the simplest case, each field oscillates only in one plane: the wave is plane polarized. When the electric field oscillates in a vertical (horizontal) plane, the wave is vertically (horizontally) polarized. Most imaging radars use an antenna that transmits horizontally polarized radiation. Upon incidence on a ground object, a portion of the returned energy retains the same polarization as the transmitted pulse while the remainder of this energy is randomly polarized (i.e., depolarized).

35. Sophisticated radar systems can transmit horizontally and vertically polarized energy. A switching mechanism in the antenna allows it to receive both the horizontal and vertical components of the return signal. Designations such as "HH" and "VV" stand for "horizontal transmit and horizontal receive" and "vertical transmit and vertical receive" respectively. Similarly, "HV" represents "horizontal transmit and vertical receive"; this is known as cross-polarized return. Polarization of the incident radiation is an important discriminating element since ground surfaces and other targets reflect differently each of the two components mentioned. For example, a simplified model of a vegetation canopy composed of vertically linear leaves (scatterers) would provide a strong reflected signal for vertically polarized incoming radiation but a very weak signal if the radiation were polarized horizontally. Thus, the return signal can provide information on the structure of the objects being viewed.

D. Sources of radar data for remote sensing

36. Launched in July 1991, ERS-1 is a low-orbit Earth observation satellite with several microwave sensors on board. The primary mission of ERS-1 is to increase the understanding of ocean processes, to monitor the polar regions and to contribute to the World Climatology Research Programme. However, an increasing number of land-oriented applications will soon result as the international research community attains access to the data. The primary instrument on board ERS-1 is the Active Microwave Instrument (AMI), which can provide high-resolution images (C-band), wind speed through ocean wave spectra

analyses and the length and direction of ocean waves. Operating in the imaging mode, AMI covers a swath of 80 to 100 kilometres, with initially assessed resolutions of 27 metres in range and 29 metres in azimuth. Preliminary assessment through October 1991 also shows high precision and replicability of the data acquired by ERS-1.

37. Operating in the wind mode, AMI covers a swath of 400-500 km over the ocean with resolution cells of 50 km and measures wind speed in the range of 4 to 24 m/s with an accuracy of 0.5 to 2 m/s. Wind speed and direction are determined by measuring the strength of the back-scattered signal of each resolution element from three directions: obliquely ahead, to the side and obliquely behind the satellite path. The intensity of the three signals provides the wind speed, and the differences between them indicate the wind direction with an accuracy of 20°. In wave mode operation, AMI determines the length and direction of ocean waves in 5 x 5 km cells for segments of 200-300 km along the satellite path. Ocean wavelengths of 100-1,000 m can be measured to an accuracy of 25 per cent and their direction to an accuracy of 20°.

38. In addition to AMI, ERS-1 carries a Radar Altimeter (RA) that operates at a wavelength of 2 cm. This altimeter looks vertically downward to measure average wave height and wind speed and to determine the meso-scale ocean topography. Data from this altimeter will be used to determine ice type and topography as well as the water/ice boundaries. ERS-1 also carries an Along Track Scanning Radiometer (ATSR) that operates in three bands in the thermal infrared region; these bands are centred around 3.7, 11 and 12 micrometres. ATSR looks through the atmosphere at the surface of the ocean from two directions, downward vertically and at an incidence angle of 50°. The difference between the oblique and vertical measurements provides information on atmospheric absorption while the differences between measurements at the three wavelengths are used to determine atmospheric water vapour content.

39. ERS-1 data is received by ESA's network of ground stations, which include Maspalomas, Spain; Kiruna, Sweden; Fucino, Italy; and Gatineau and Prince Albert, Canada; as well as by a number of ground stations located in the industrialized and developing countries. User requests for acquisition of ERS-1 data over a particular area of the Earth or requests for specific products of ERS-1 data already acquired are channelled through ESA's Earthnet Central Facility (EECF) located in Frascati, Italy. The EECF supports the cataloguing and archiving of ERS-1 data acquired and provides a browse option that is available to the users.

40. To date, most of the radar data collected worldwide have been obtained by airborne radar systems. Even with the arrival of radar satellite systems, aerial systems will continue to provide data to meet specific user-determined acquisition parameters, particularly flight direction, viewing angle and high spatial resolution. The C/X-SAR sensor was planned and integrated on board its Convair 580 aeroplane by the Canada Centre for Remote Sensing (CCRS). This system was designed and built by MacDonald-Dettwiler Ltd. and Canadian Astronautics Ltd., to operate in the C- and X-bands for use by the research

and development community. This SAR sensor is capable of imaging the Earth's surface in three modes: nadir, narrow and wide swath. At its optimum operating altitude of 6 km, the C/X-SAR sensor can provide a ground resolution of 6 m x 6 m over depression angles from 16° to 90° (nadir mode) or 14° to 45° (narrow swath). The nadir mode is useful in terrain of high relief or for simulation of satellite SAR geometry.

41. Although the bulk of the satellite radar data that will be acquired over at least the next 10 years will be obtained in the C-band, most of the experience developed to date has been with radar operating in the X-, L- and K-bands. Airborne radar such as the C/X-SAR can also be used to investigate the use of C-band radar in monitoring the Earth.

42. A project aimed at studying the use of C-band data over moist tropical forests and their environs was proposed by Canada during the First Space Conference of the Americas, held at San José, Costa Rica, during 1990. As a result, a SAR data acquisition mission for this purpose has been organized and is under way under the auspices of ESA. In 1992, the mission will acquire C-band data over a number of Latin American countries using the CCRS Convair 580 aircraft. The main objectives of this regional cooperation project are to determine the ability of C-band SAR data to detect and map forest cover types, clearings, burned areas and forest regeneration, extent of flooding, agriculture distribution, natural dams and rivers caused by rock slides and landslides and various other types of surface changes. The project will document the results of these investigations to promote the knowledge of radar among professionals and technical staff responsible for management of natural resources and the environment in the region.

43. Airborne radar data have also been collected over various regions around the world, including Peru and other regions of Latin America, by two other SAR instruments operated on a commercial basis by Intera Kenting, Canada. The STAR-1 (Sea-Ice and Terrain Assessment Radar) system, developed in 1983, and the STAR-2 system, developed in 1987, are fully focused X-band Synthetic Aperture Radars with real-time processors on board the aircraft. The characteristics of both instruments are similar, with the major performance difference being in their range resolution. STAR-1 can provide a maximum ground resolution of 6 m x 6 m while STAR-2 provides a 5.4 m x 4.0 m resolution when operated in narrow swath mode. In this mode and flying an altitude of 7.0 km, the STAR systems view a swath width of 18 km and adjacent flight lines produce an overlap of 10 km strips; this permits stereo reconstruction of the terrain. In the absence of ground control points, the aircraft use navigational information and an on board Global Positioning Systems (GPS) to relate aircraft coordinates to image coordinates. Topographic mapping products at scales of up to 1:50,000 can then be created utilizing algorithms that enable the radar image pixels to be geocoded.

44. Data from STAR-1 and STAR-2 have been used in commercial applications to mineral and petroleum exploration. Radar data have been used to create Digital Elevation Models (DEMs) of the terrain and orthorectified radar images with elevation contours overlaid on them at a 1:50,000 scale. For regions

with little or no cartography these products can be used as planimetrically accurate base maps, topographic representations and as source data for thematic (geological) interpretation. In particular, these products can be used by planning teams and field crews for laying out seismic lines in the foothills, by helicopter-borne teams performing geological field sampling and by geophysicists who use DEMs for interpretation purposes. The geological information that can be extracted from radar images includes terrain relief, regional lineaments, joints, fractures, folding, anticlinal and synclinal structure and drainage patterns.

45. Other SAR data, obtained by the SEASAT satellite (1978), the Shuttle Imaging Radar-B (SIR-B) and Aircraft SAR (AIRSAR) mission of the United States are kept in the archives of the Radar Digital Processing Group at the Jet Propulsion Laboratory (JPL) at Oak Grove, California. Information on the characteristics of the missions and on the data obtained by them can be accessed through JPL's SAR Data Catalogue System (SDCS), from a remote terminal. The SDCS also contains an on-line inventory of digital terrain data that is kept in the archives at JPL.

E. Digital image processing and analysis

46. The capability to digitally process large volumes of data with uniform criteria, and often data that have been enhanced or which include new bands as a result of linear transformations of the original ones, allows the routine monitoring of large areas and the attainment of a finer discrimination between classes in the scene.

47. Satellite image data as provided to the users does not generally represent the surface of the Earth with the geometric fidelity necessary for topographic maps and does not usually fit into existing standard map projections. This is due to effects that are introduced by changes in attitude, altitude and spacecraft velocity, non-linearities in the sensor scan process, unequal sensor response, effects of the Earth's curvature and rotation and elevation of the satellite over the Earth's surface. Most of these effects (the systematic ones) can be compensated for during the preprocessing geometric and radiometric correction stage; this is done more efficiently using a digital process.

48. Digital image enhancement improves the visual presentation of the information content of the image. These techniques assist in a visual interpretation or in reducing the amount of digital data to be processed but do not create any new or additional information. Common techniques include the following: contrast enhancement, spatial filtering, linear band combinations and principal component transformations. Since in any image the full dynamic range of values that the pixels could take (typically from 0 to 255) is not utilized, the contrast of the entire image can be digitally improved. A typical range of values in an image is of the order of 80 so that the contrast can be improved visually by a factor of 3. Low-pass and high-pass filters are used to smoothe out the local variations of radiance

values or to enhance reflectance differences, particularly at borders between two classes of objects. Principal component transformations are a way of reducing the number of data of a set of images while retaining the most significant information. Linear band combinations include generating a new band from the ratio of two bands or the ratio of the difference of two bands to the sum of the same bands; these transformations, and many others that might be performed, enhance features of interest to the interpreter.

49. The final output of the evaluation of remote-sensing data is a thematic image (or map) of the scene analysed depending on the specific interest of the interpreter. The process of achieving this through digital processing is called "classification". Two different approaches to digital image classification have been developed: supervised and unsupervised classification. The first approach requires that the interpreter identify areas representative of the classes to be included in the thematic output in order that the classification algorithm may use statistical parameters to classify each pixel in the image into one of the classes requested. Unsupervised classifiers require little interaction by the user and are based entirely on statistical methods. The rationale behind the latter approach was to make the classifications independent of the skill of the user. However experience has shown that the quality of the supervised classification is usually better since the experience accumulated by the user is more fully utilized.

F. Remote-sensing applications

50. In hydrology, the most useful applications of remote sensing are in locating and conducting inventories of water resources, determining land cover and assessing wetland areas. Various rainfall run-off models currently used for hydrologic modelling were developed before the advent of remote sensing and are based on the use of topographic maps. The use of Digital Terrain Models and topographic images that can be constructed based on data from SPOT and from various radar systems would improve estimates of the amounts and spatial distribution of rainfall losses, particularly over regions where conventionally obtained topographic maps are not available.

51. Other key parameters that need to be determined for hydrologic modelling are: (a) soil moisture, (b) evaporation, (c) land cover, (d) impervious surface area, (e) extent of snow cover and the water equivalent of snow and (f) precipitation. Of these parameters, soil moisture, precipitation and evaporation are the most difficult to obtain. However, the use of remote-sensing data obtained in the visible, infrared and radar portions of the electromagnetic spectrum now permits accurate estimates to be determined for the values of these parameters, although not yet on an operational basis.

52. Meteorology is an area in which there has been a marked improvement in the accuracy of estimating the key parameters. Meteorological parameters are not only important for weather forecasting and atmospheric modelling but are also of great value in hydrology and agrometeorology. A number of techniques

have been developed to estimate rainfall occurrence and intensity based on satellite data obtained in the visible and thermal infrared (TIR). These techniques are based on observational evidence that shows a correlation between the brightness of cloud tops as seen in visible and infrared images and rainfall. Bright cloud tops as seen in the visible range produce more rainfall than darker clouds. Bright clouds in the visible with colder tops (TIR information) and which are expanding in areal coverage produce more rainfall. Most of the rain occurs in the upwind portion of a growing cloud system where higher clouds with colder tops form in the region of most vigorous convection. The growth of a thunderstorm system and the direction of movement of the clouds are determined from half-hourly meteorological satellite images. Thus, these interpretation techniques are fully operational.

53. Soil moisture can be defined as the temporary storage of precipitation within a shallow layer of the Earth that is generally limited to the zone of aeration or root zone. Although the amount of water in this layer is insignificant when compared to the total amount of water available on a global scale, it is this layer that controls the success of agriculture. However, in spite of its importance, soil moisture is seldom used in the prediction and monitoring of crop productivity because of the difficulty in its determination. Soil moisture is difficult to measure by any means, in a way that is representative of large areas; such measurements are valid only at the place where they are obtained. For agricultural applications, determinations of temporal and spatial differences of soil moisture may be more important than the actual absolute value of soil moisture.

54. Soil moisture is one of the parameters of importance to agriculture which are currently the subject of SAR research. Other key soil parameters where radar could provide valuable information are its roughness and the tillage direction. SAR research is also being conducted on determining the parameters of a plant canopy. These canopy parameters include plant height and density, canopy structure and plant row direction, growth stage, leaf area index and plant biomass and its water content.

55. Along with LANDSAT, SPOT and AVHRR (Advanced Very High Resolution Radiometer) data, satellite SARs are potentially a very useful source of data for crop information systems. Together, these sensor systems span the EM spectrum from the visible and near infrared through the thermal infrared and the microwave regions. The new challenge will be to integrate the data, with different spatial and temporal resolutions, into a complementary system that can provide the continuous information necessary to monitor crop development and to do so in an operational manner.

G. Geographic Information Systems

56. The information derived from each of the various remote-sensing systems is in most cases used for a specific application. Beyond that application, the derived data can be considered raw information that can be used with other information in a Geographic Information System (GIS) for management and policy-making decisions. The sources of data for a GIS are the following:

remotely sensed data, point measurements such as field-obtained data, existing cartography and statistical or census-type information. The important characteristic of a GIS is that all the data contained in it have positional references, usually geo-coded to corresponding points on the Earth's surface.

57. A GIS can be defined as consisting of the following three basic elements: (a) a large amount of data which have spatial or locational characteristics; (b) an integrated set of programs which distinguishes the GIS from a series of unrelated individual programs; and (c) a common set of sub-components which perform such operations as data storage, retrieval, analysis and display. From a user's point of view a GIS is a relational type of database, spatially indexed in such a way that new information can be added from external sources or created from existing information.

58. A GIS is visualized as consisting of a number of layers, each of which contains thematic information on one or more variables over the surface area being considered. Through user-defined queries, the system can superimpose all or a subset of the layers to produce an output in the form of a tabular or statistical report or as an image either on a television monitor from which a hard copy could be made or in digital form on magnetic tape to be used to generate a map-like product. An example of a final product of a GIS query might be an image display showing the location and areal extent of three soil types in areas with slopes of less than 10° that receive an annual rainfall of at least 400 mm during a six-month period and are less than 50 km from population centres of at least 50,000 inhabitants.

59. A GIS product such as the one indicated above could be used for planning purposes as, for example, in identifying new agricultural areas for particular types of crops and to locate distribution points for the types of fertilizer that would be required. Another important use for GIS products is the use of their products as information for predictive models. While these models would not indicate actual future conditions, they would be capable of indicating the conditions that might be expected if a particular trend (e.g., land degradation) continued at the current rate, or if particular climatic conditions occur (e.g., drought/flooding associated with the El Niño phenomenon). If the appropriate information is input into its database, a GIS can be used to evaluate or predict complex scenarios involving many parameters in a fast and reliable manner. A GIS could be the basis for specialized information systems such as an agricultural information system, a forestry resources information system or an environmental impact information system.

II. EVALUATION OF THE COURSE

60. At the conclusion of the course, the participants were asked to complete a questionnaire regarding various aspects of the organization of the course, the time allotted to the topics and practical exercises as well as the relevance of the course to their current and future activities in their respective agencies. This exercise was followed by a round-table discussion, including both participants and instructors, on the accomplishments of the course and recommendations for future courses.

61. An analysis of the completed questionnaires shows that the participants were of the opinion that the organization, planning and delivery of the presentations of the course were of high quality. Approximately 50 per cent of the participants felt that more time should have been allotted to practical exercises in digital image processing. Depending on their field of expertise, some participants felt that more time should have been allotted to that applications area. The majority of the participants indicated that the level and content of the training course were appropriate for the specific needs of their work. They were unanimous in expressing their appreciation to the Government of Peru and to the United Nations, the World Meteorological Organization and the European Space Agency for having organized and sponsored the course and expressed their desire for additional training in the use of radar remote sensing.

Annex

PROGRAMME OF THE COURSE

Date	Time	Subject	Speaker
Monday, 7 October	9-9.30 a.m.	Registration	
	9.30-10 a.m.	Opening ceremony	
		Welcome address	
		United Nations	S. Camacho
		World Meteorological Organization	G. O. P. Obasi*
		European Space Agency	J. P. Guignard
		Peru	R. Coloma
	10-10.45 a.m.	Keynote address: Remote sensing in resource management and environment protection	R. Coloma CONIDA
	11 a.m.-12.30 p.m.	Overview of remote sensing	S. Camacho United Nations
	2-5 p.m.	Fundamentals of electromagnetic radiometry	S. Camacho United Nations
Tuesday 8 October	9-10.30 a.m.	Characteristics of satellite Earth-observation systems	J. P. Guignard ESA
	10.45 a.m.-12.15 p.m.	Characteristics of meteorological satellite systms (geostationary and polar)	J. P. Guignard ESA
	2-3.30 p.m.	Principles of image formation (data acquisition, digital/analog representation, display techniques)	F. Quispe CONIDA
	3.45-5 p.m.	Spectral, spatial and temporal image resolutions	R. Coloma CONIDA

* A statement from Prof. G. O. P. Obasi, Secretary-General of WMO, was read at the opening ceremony.

Date	Time	Subject	Speaker
Wednesday 9 October	9 a.m.- 12.15 p.m.	ERS-1 microwave sensors from a mission viewpoint	J. P. Guignard ESA
		Orbits and instrument characteristics	
	2-5 p.m.	SAR principles; radar data processing and ERS-1 products	J. P. Guignard ESA
Thursday 10 October	9 a.m.- 12.15 p.m.	ERS-1 results: two months into operation	J. P. Guignard ESA
	2-5 p.m.	Applications of current ERS-1 data	J. P. Guignard ESA
		Discussion on using ERS-1 products	
Friday 11 October	9-10 a.m.	Use of the RESORS information system	R. Coloma CONIDA
	10 a.m.- 12.15 p.m.	Recognizing and evaluating soil erosion and degradation	V. Barrena Univ. Agraria
	2-5 p.m.	Case-study related to the morning session	V. Barrena Univ. Agraria
Monday 14 October	9-10.30 a.m.	Digital image formation and diagnostics	T. Alfoldi CCRS
	10.45 a.m.- 12.15 p.m.	Digital image preprocessing and corrections	T. Alfoldi CCRS
	2-5 p.m.	Visit to the facilities of Oficina Nacional de Evaluación de Recursos Naturales (ONERN)	Z. Rodriguez ONERN
Tuesday 15 October	9 a.m.- 12.15 p.m.	Principles of digital image analysis - enhancement and classification	T. Alfoldi CCRS
	2-5 p.m.	Practial exercises on digital images	T. Alfoldi CCRS
Wednesday 16 October	9-10.30 a.m.	Principles and development of radar	J. Sutton Intera Kenting
	10.45 a.m.- 12.15 p.m.	Characteristics of Synthetic Aperture Radar-imaging geometry	T. Afoldi CCRS

Date	Time	Subject	Speaker
	2-3.30 p.m.	Target parameters and radar systems	J. Sutton Intera Kenting
7	3.45-5 p.m.	Radar image characteristics	J. Sutton Intera Kenting
Thursday 17 October	9 a.m.- 12.15 p.m.	Radar applications in geology and oceanography	J. Sutton Intera Kenting
	2-3.30 p.m.	Radar applications in hydrology	T. Alfoldi CCRS
	3.45-5 p.m.	Practical exercises on radar data applications to geology	J. Sutton Intera Kenting
Friday 18 October	9-10.30 a.m.	Radar applications to agriculture	J. Sutton Intera Kenting
	10.45 a.m.- 12.15 p.m.	Radar applications to forestry	T. Alfoldi CCRS
	2-3.30 p.m.	Practical exercises on radar applications to forestry	T. Alfoldi CCRS
	3.45-5 p.m.	Overview of radar systems and applications	T. Alfoldi J. Sutton
Monday 21 October	9-10.30 a.m.	Estimation of rainfall and run-off	N. Ferreira INPE/WMO
	10.45 a.m.- 12.15 p.m.	Applications of remote sensing to agrometeorology	N. Ferreira INPE/WMO
	2-5 p.m.	Practical exercises related to the morning session	N. Ferreira INPE/WMO
Tuesday 22 October	9-9.45 a.m.	Principles of Geographic Information Systems (GIS)	S. Camacho United Nations
	9.45 a.m.- 12.15 p.m.	Structure of a GIS	V. Barrena Univ. Agraria
	2-5 p.m.	Input of satellite, cartographic and tabular data into a GIS	V. Barrena Univ. Agraria

Date	Time	Subject	Speaker
Wednesday 23 October	9-10.30 a.m.	Products derivable from a GIS analysis	V. Barrena Univ. Agraria
	10.45 a.m.-12.15 p.m.	Case-study: GIS applications to agriculture	V. Barrena Univ. Agraria
	2-5 p.m.	Student project: practical exercises utilizing the entire contents of the course	United Nations/ WMO/CONIDA/ Univ. Agraria
Thursday 24 October	9 a.m.-12.15 p.m.	Student project (continued)	
	2-5 p.m.	Student project (continued)	
Friday 25 October	9-10.30 a.m.	Discussion of the student project	
	10.45 a.m.-noon	Course evaluation	United Nations
	Noon-12.30 p.m.	Closing ceremony	Co-sponsors